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THE COST OF CONCRETE TUNNEL LINING AND OF TUNNEL EXCAVATION.

By Geo. W. Lee.* Jun. Am. Soc. C. E.

While a great deal of information has been written regarding the cost of concrete work and methods of its construction, the majority of these articles have related to arch culverts and abutments, and as little has been said regarding the actual cost of concrete tunnel lining it may be of interest to have figures showing the cost of this style of work and to know the methods used in construction.

The tunnel referred to in this article is a comparatively short one, being but 275 ft. long from portal to portal, and consequently the work was carried on by methods which could not be used on one of considerable length. The entire tunnel, which is located about 2½ miles north of Peekskill, N. Y., on the New York Central & Hudson River Railroad, is through the well-known rock formation found along the Hudson Valley, and the tunnel section was taken out from 6 ins. to 3 ft. outside the concrete section.

It may be stated also that the tunnel was made through a projecting steep rocky spur, and was planned to improve the alinement of the railway, which formerly ran closer to the river bank, and just skirted the base of the spur.

The foundation trenches were excavated from 1 ft. to 3 ft. deep, and the foundation was leveled up with concrete composed of 1 part cement to 2 parts sand, to 4 parts of crusher-run stone, of the size to pass a 1-in. ring. The back of the foundation was carried to the rock section, but the front was lined to forms giving a 12-in. offset to the bench wall. The foundation contained 200 cu. yds.

As soon as the foundations were complete, platforms 25 ft. square were erected level with the springing line and at each end of the tunnel. A stiff leg derrick with 40-ft. boom and double-drum hoisting engine was next set up near each platform and placed to handle skips from the material track to the mixing platforms. The material track ran under the mixing platforms and through the tunnel, and a turnout was laid beyond each portal for switching back the empty cars.

A 60-HP. horizontal boiler on wheels furnished the steam for the hoisters and for a pump which supplied water to the mixing platforms. The bench wall forms were built in 12-ft. sections with plates and sills of 4 × 6-in. and studs of 4 × 4-in. hemlock, spaced 3 ft. c. to c. Sheathing was of 2-in. dressed and matched spruce. Four of these sections were set in place on each foundation at the center of the tunnel. Wheelbarrow runways carried on bents were set up from the mixing platform to them, one extending from the south platform to one side and the one from the north to the other.

The forms were braced to the track in the center of the tunnel. Buttresses were built at the end of the forms and the concrete brought up to the springing line. The bench wall was not carried back to the rock, but back forms of 1-in. hemlock were used and the space left was filled with spalls, allowing the seepage through the rock, which was considerable during rainy weather, to run off through the weep holes, which were placed every 15 ft. along the bottom of the bench wall.

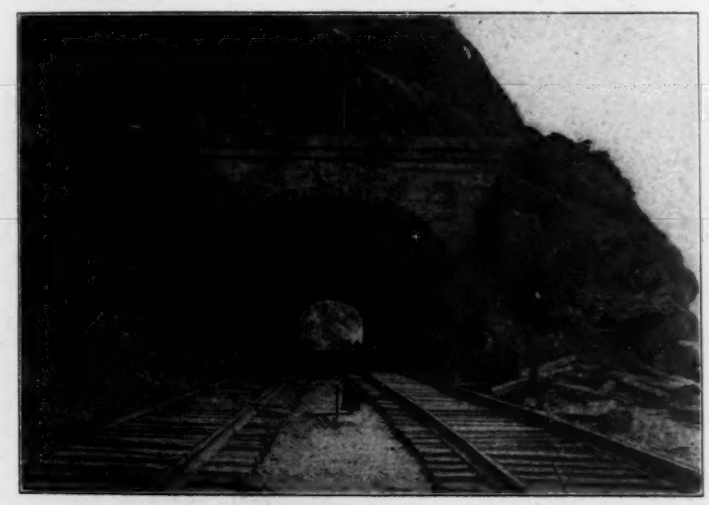
While the concrete was being placed, carpenters were setting other forms on each side toward the platforms, from which the concrete was being wheeled, and these were in place by the time the first sections were filled. The forms for bench wall sections were removed the day after the concrete had been placed and the surface was rubbed smooth with wooden floats. The bench walls were carried in this way to the portals and ended in sandstone masonry.

Arch forms were then erected for a distance of 96 ft. in the center of the tunnel, the lagging being laid in 12-ft. lengths, so that later these arch forms might be moved forward in sections of that length, nine toward the north and nine toward the south.

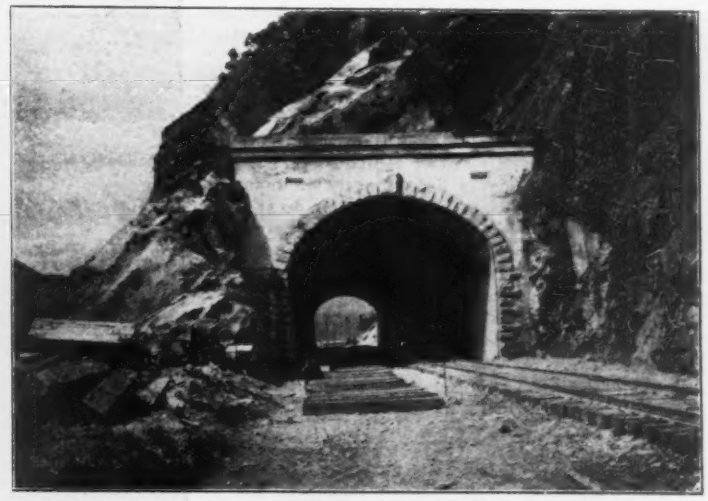
The lagging was at first laid only up to a height of 3 ft. above the springing line, and the concrete was wheeled in on runways laid over the lower chords of the ribs, and dumped in place, the ribs being spaced 4 ft. c. to c. to allow this. When the concrete had been built up too high for dumping direct in the forms, it was dumped on the runways and passed in with shovels. On the upper portion of the ring the concrete was first shoveled to a platform erected on the center posts of the ribs, about 2 ft. below the crown, and then passed in on the lagging, which was laid in 4-ft., instead of 12-ft., lengths at this period of the work. The lagging was kept just ahead of the concrete during all the work on each section, which gave room for the tampers and shovelers to work until the arch was all keyed, except the forward 4 ft., the material being then passed over the buttress forms.

The arch forms were removed in a comparatively short time, and in one case the last section had been keyed but 90 hours when the forms were lowered. Careful measurement, however, on this section failed to show any settlement at the crown. In moving the forms ahead, it was found necessary to jack them down on account of the concrete sticking to the lagging. This was done by chiseling out a part of the lagging at the crown and setting jacks against the concrete and cross-pieces spiked to the rib posts. The forms were hauled ahead by passing the main fall of the

*Engineer for Sundstrom & Stratton, Contractors, 143 Liberty St., New York City.



North Portal.



South Portal.

PORTALS OF TUNNEL ON NEW YORK CENTRAL & HUDSON RIVER R. R. NEAR PEEKSKILL, N. Y.

derrick through a snatch block to the first rib, and when they were clear of the concrete all the lagging was removed except the lower 3 ft. The ribs were then wedged up to place and the work proceeded.

The arch section was waterproofed by six layers of tar paper laid in hot tar, and in most cases the rock had been taken out far enough to allow this to be done carefully. The space above the arch was then packed with spalls. The work of packing and waterproofing was carried on as fast as the sections of arch were completed.

The bench walls contained 692 cu. yds. and the arch ring 932 cu. yds. Both bench walls and ring were of the same class of concrete as the foundation (1:2:4), but the portal head walls were of 1 part cement to 3 parts of sand to 6 parts of stone. and in all 1,948 cu. yds. of concrete were placed, the cost of which is shown by the following table:

Cement at $1.63		$5,755.50
Sand at 75 cts.		662.94
Crushed stone at 80 cts.		1,303.20
Lumber:		
Mixing platforms and runways	$336.89	
Ribs, including band sawing	234.10	
Backing boards	134.44	
Lagging	341.04	
Sheathing	268.49	
Plates, sills, studs and braces	182.75	
	1,497.71	
Coal	118.73	
Oil	16.12	
Hardware, nails, spikes, etc.	224.39	
Tools	181.10	
Freight on stone, cement, etc.	3,089.86	
Labor, including superintendent, foreman, timekeepers, etc.	8,036.31	
		$20,885.76

Average cost per cu. yd., $10.72.

The yardage of rock in the tunnel measured to the proposed excavation line was 7,028 cu. yds., but the rock lay in strata of nearly 45° inclination, and on the up-hill side broke out in such a manner as to leave large pockets in places. The total yardage taken out was 7,791 cu. yds., and the contractor, therefore, lost payment on nearly 10% of the total excavation.

The headings were driven through 8 ft. × 10 ft., and the bench was kept as close to the heading as possible.

As shown in the accompanying photographs, the west line of the tunnel was very close to the slope of the mountain being but from 10 ft. to 18 ft. in most places. Owing to this and the seamy condition of the rock, the railroad company early in the work insisted on very light charges of dynamite being used. This, of course, greatly de'ayed the progress of the work and considerable expense was added later when, owing to a change in the grade of the tunnel, the contractor was forced to go back to the portals and take off an extra foot from the roof. At one time all work was suspended in the south heading on account of the loosening of a large shelf of rock over the portal.

In removing the rock from the tunnel, narrow gage push cars loaded by hand were used for the spoil from the headings while the rock from the benches was loaded on standard gage cars with derrick cars. These derrick cars were made on the work by setting up short stiff leg derricks and double drum hoisting engines on flat cars. No. 3 Rand drills were used on the tunnel and approaches, steam being used for power.

In the approaches of the tunnel and in widening cuts south of the tunnel, 45,698 cu. yds., of rock were removed. On account of the proximity to main line traffic, blasting could only be done at certain limited periods and this of course made the cost of excavation more than where such conditions do not prevail.

Over fifty passenger trains and a large number of freight trains passed close to the work every day, but the excavation was carried out with the delay of but one train, and that one for but a few minutes, when a large rock, loosened by a blast, fell and broke a derrick.

The plant used to load the rock from the side hill cuts, which ran up to 50 ft. in height, was composed of heavy stiff leg derricks operated by double drum hoisting engines. The derricks were equipped for quick, heavy work, bull wheels and swinging gears being attached. The rock was placed on flat cars which were taken away by the railroad company and the material used for rip-rap.

The following is a tabulated statement showing the cost of tunnel and cut excavation.

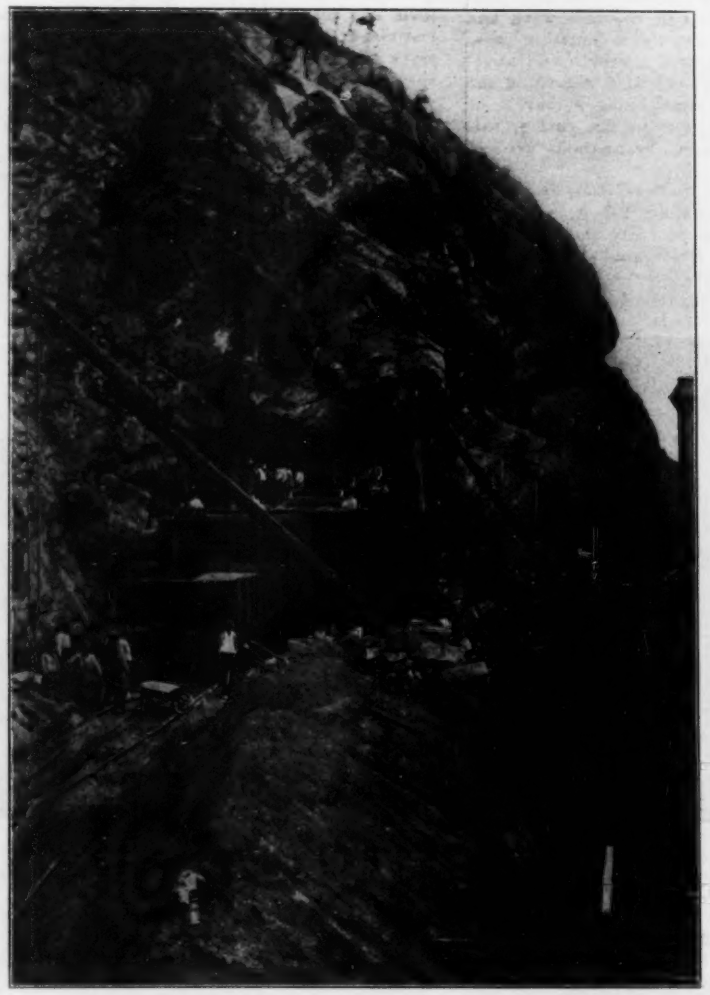
TUNNEL.

Equipment (less present value) supplies and repairs	$2,893.52
Dynamite and exploders	1,604.58
Coal	570.80
Oil, waste, etc.	92.80
Lumber for office, powder houses, blacksmith shops, etc.	129.88
Miscellaneous	92.10
Labor.	22,212.86
Total	$27,596.54
Average cost, considering actual yardage taken out.	$3.54
Average cost, considering yardage paid for.	3.93

TUNNEL APPROACHES AND ROCK CUTS.

Equipment (less present value) supplies and repairs.	$11,673.60
Dynamite and exploders.	6,588.82
Coal.	2,490.13
Oil, waste, etc.	370.59
Lumber for office, powder houses, blacksmith shops, etc.	634.22
Miscellaneous.	373.19
Labor.	69,550.66
Total	$91,681.21
Average cost, considering actual yardage taken out.	$2.01
Average cost, considering yardage paid for.	2.24

The work of excavation and masonry as above described was done by Sundstrom & Stratton, Railroad Contractors, 143 Liberty St., New York City, under the direction of Mr. H. Fernstrom, Chief Engineer of the New York Central R. R. Co. Mr. K. C. Weeden was Resident Engineer, and Mr. J. D. Matheson, Engineer in charge for the railroad company. The writer acted as engineer for the contractors.



VIEW OF NORTH PORTAL OF TUNNEL DURING CONSTRUCTION.

STONE BALLAST.

By E. A. Hermann,* M. Am. Soc. C. E.

The increasing weight, speed and frequency of trains passing over our railroads is being followed (though it should have been preceded) by a better and stronger track. Heavier rails are already quite generally used and better ballasting is making rapid progress; only the rail fastenings show no marked improvement.

The distribution of the immense moving loads, concentrated at the wheel treads, over the greatest possible area of subgrade is the essential requirement of a track ballast. Other requirements demand a material which will offer great resistance to crushing, which can be readily tamped under the tie and packed about its sides, which will permit rain water to percolate through it and drain away into subdrains, side ditches or off embankments, and which will not produce dust under passing trains. It is now quite generally admitted that broken stone is the only material which fulfils all these conditions.

Most of the older railroads and those passing through mountainous or hilly country, where rock cuts are frequent and stone ballast easily obtained, have long ago ballasted their tracks with broken stone, and the tendency on nearly all other railroads carrying fast and heavy traffic points to the early replacement of their sand, cinders, burned clay or gravel ballast with crushed stone. This seems to apply especially to the main lines of those railroads in the central Mississippi valley whose traffic has lately assumed a trunk line character. A large amount of such work has been done in the last few years (and is still under way) and much more of it is in view for the near future.

A sound, hard stone is required for a good ballast; limestone and trap rock are most commonly used. The broken stone should not exceed 2½ ins. in greatest dimensions. Some railroads accept the run of the crusher, but the majority require that the product of the crusher shall be screened and all dust and stones less than half-inch cubes shall be excluded.

The ballast is usually 1 ft. thick under the ties, about 9 ins. of which consists of stones from 1½ to 2½ ins. in greatest dimensions, and the balance of smaller stones, the latter being also used between the sides of the ties and for 6 ins. beyond their ends. The smaller stones near the top of the ballast are essential for properly tamping stones *under* the ties, and not wedging against the sides of the ties only as is so commonly done where only large sizes of stones are used, and thus properly supporting the tie *from underneath*, giving each tie a firm and uniform support, thereby preventing churning of ties and excessive wave motion of the rails ahead of and under the moving load. The use of a layer of the smaller stones near the top of the ballast also greatly facilitates the renewal of ties.

Crushed slag has many of the advantages of stone ballast, but its use is necessarily confined to the immediate vicinity of the locality of its production, an area so small that it may almost be considered a negligible quantity.

The superiority of crushed stone over any other material for track ballast is based upon the following claims:

1. It constitutes a solid mass, the stones interlocking and binding each other immovably, thus

*Consulting Engineer, Room 812, Security Building, St. Louis, Mo.

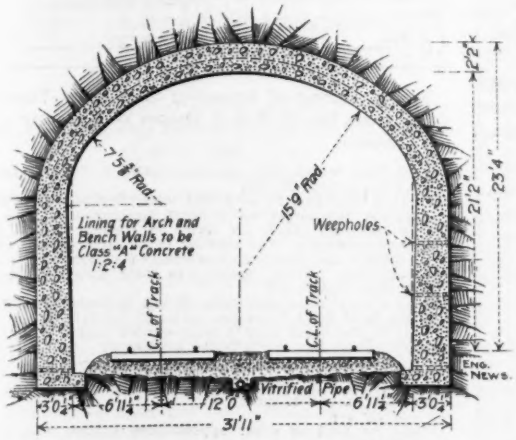
forming practically a solid supporting body which distributes the moving load over the largest possible area of the subgrade.

2. It offers the greatest resistance to destruction, crushing or grinding, of any material practically obtainable for this purpose.

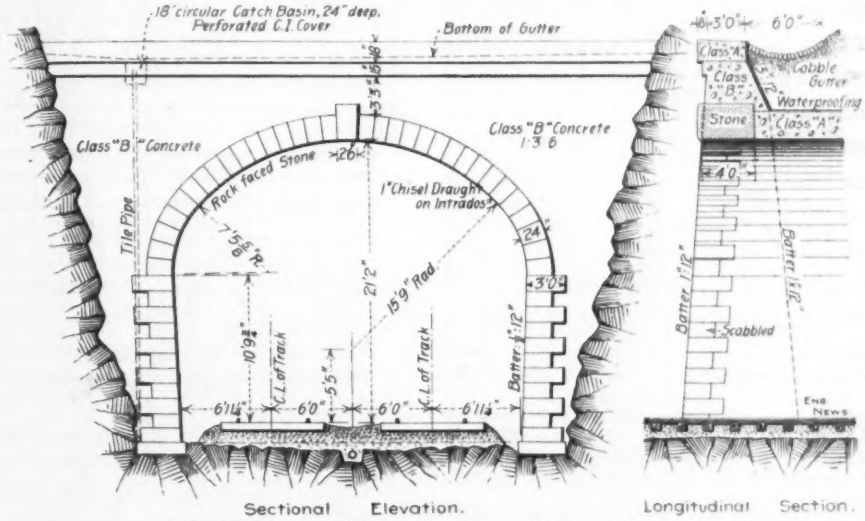
3. It can be readily tamped *under* the ties and packed about their sides, thus supporting the ties firmly and uniformly and preventing to the greatest possible extent all vertical, side or endwise motions of the ties, thereby avoiding undue wave motion of the rail ahead of and under the moving load and also preserving the line and surface of the track.

4. It will permit rain water and melting snow to drain away readily.

5. It does not provide sustenance for weeds on the track, and thereby saves the large cost of frequently removing such growths.



Cross-Section of Peekskill Tunnel, Showing Lining.



ELEVATION AND SECTION OF PEEKSKILL TUNNEL PORTAL.

6. It is moderate in first cost.

7. It is the most economical in operation and maintenance.

8. It is free from dust; a large saving in the operation and maintenance of the rolling stock, and also of considerable value for advertising purposes.

9. It is shunned by trespassers, both man and beast.

10. It interferes least with electric track circuits for signaling or other purposes.

11. It is usually white or light gray in color,

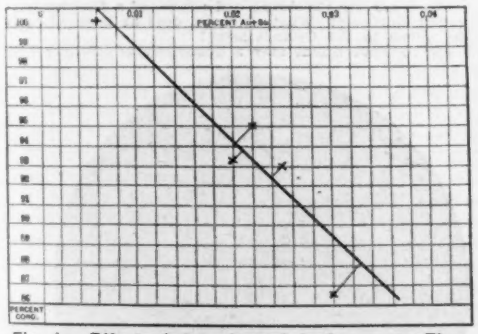


Fig. 1. Effect of Arsenic and Antimony on Electrical Conductivity of Copper.

and foreign objects on the track may be most easily seen at night.

12. It is the most neat and clean in appearance.

THE ELECTRICAL CONDUCTIVITY OF COMMERCIAL COPPER.*

By Lawrence Addicks, Assoc. M. Am. Inst. Elec. E.†

Electrical conductivity has come to be a universally accepted measure of the degree of purity of copper for two reasons: First, on account of the enormous quantities of copper used in electrical construction; second, because the conductivity forms a very delicate test of the chemical purity of the metal. Furthermore, a conductivity test may be made upon a wire of suitable dimensions in about three minutes, while a chemical analysis of refined copper is a tedious and correspondingly expensive operation.

Matthiessen's standard (one meter-gramme of pure soft copper at 0° Centigrade = 0.14172 international ohms), has come into very general use, although it is some 3% too low. The fact that the quality of the copper on the market to-day often exceeds in purity by as much as 1% the purest laboratory copper of forty years ago forms an interesting commentary on the excellence of modern methods.

Conductivity is affected by the physical state of a metal or alloy as well as by its chemical constitution. Now in order to obtain the sample of wire upon which a measurement is made, the copper under examination must be subjected to several mechanical processes, and these different variables must be taken into account. It is the purpose of this paper to point out their influence.

First, let us take up the influence of the chemical impurities commonly met with. These consist of oxygen in the form of suboxide of copper, arsenic, antimony, and (in some coppers) bismuth. Small quantities of some other elements may be met with, but those mentioned are the impurities to be looked for in low copper.

The relation between arsenic or antimony and conductivity is shown in Fig. 1. As arsenic and antimony have a very similar influence the data have been gathered as arsenic plus antimony, thereby greatly simplifying the work. The suboxide of copper is practically constant in all these determinations. The conductivity is stated for annealed samples of wire. It will be noticed that $^1/_{100}$% of arsenic or antimony lowers the conductivity about 6%.

Fig. 2 shows the relation between suboxide and conductivity in annealed wire. The suboxide has been calculated from the oxygen, itself obtained by subtracting the percent copper by analysis from 100. The quantity of other impurities present is so small that this is substantially correct. The crest of the curve shows copper "in pitch" or "set" or when sufficient oxygen is retained to keep the impurities as oxide, in which state they are supposed to be less harmful. The possible formation of a carbide or the absorption of hydrocarbon gases from "overpoling" in the refining furnace has also been suggested.

We come now to the physical characteristics and their influence upon the conductivity. We can cause considerable changes in structure by mechanical operations and, as would be expected, the conductivity is affected thereby, but by no means as seriously as by arsenic or antimony. The operation most commonly met with is that of wire drawing—conductivity varies with hardness. In Fig. 3 conductivity and tensile strength are plotted against the percentage reduction in area of a wire rod after annealing, and in Fig. 4 conductivity is plotted directly with tensile strength. It will be seen that the tensile strength varies almost directly as the reduction in area and that the conductivity drops about $^1/_{10}$% for every 1,300 lbs. gain in tensile strength, a fact which must be taken into account when comparing different samples of hard-drawn wire. Fig. 4 also shows results obtained where a hard-drawn wire is given different degrees of annealing. This ratio, shown by the angle of inclination of the straight line to the axes, is independent, in so far as the writer's investigations have extended, of the actual conductivity of the annealed wire, which is of course dependent upon chemical purity.

Fig. 5 shows the effect of temperature in the annealing operation. A 12 B. & S. hard-drawn wire has been heated to various temperatures by being forced to carry currents from zero to a fusing current of about 220 amperes. The actual temperatures were not measured at the time the tests were made. Very roughly the temperature in degrees Fahrenheit will be about ten times the values shown for amperes. In the experiments quoted about ten feet of wire was put in series with a water rheostat and the whole shunted around forty or fifty volts of a 4,000-ampere circuit. The current was adjusted by acidifying the water in the rheostat and was left on in each case until it reached a steady value—a matter of about a minute. The time during which the current was on, after this steady heat was reached, seemed to exert no other effect than to increase the shell of scale formed on the wire.

The question at once arises whether the lower conductivity due to overheating is caused by the absorption of oxygen in some way or to a crystalline change. The first idea that suggested itself was to anneal the wire in such a way that oxygen could not attack it. Handling white-hot wire of the length needed in an atmosphere of nitrogen proved somewhat troublesome, however, and was left as a last resort. Silver-plated wire was tried but the plating would not stand the temperature. Finally the problem was attacked in two different ways: First, samples of burned wire were immersed in dilute nitric acid until the diameter was considerably reduced and then measured for conductivity. No appreciable difference was found, showing that any chemical change was at least uniform throughout the wire; secondly, samples of burned wire were drawn to a smaller size, reannealed properly and then tested. The original wire, when properly annealed showed 100.4% conductivity; when burned for the test, 99.1%; and when drawn down and reannealed properly, 100.5%. These results show the change to be of a physical, not chemical nature.

Figs. 6, 7 and 8 are micro-photographs of copper samples which have been polished and etched in 50% aqua regia for about 30 seconds. The magnification and the

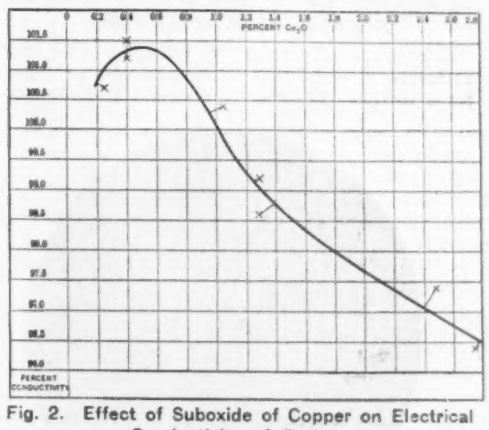


Fig. 2. Effect of Suboxide of Copper on Electrical Conductivity of Copper.

size of rod fram which the samples have been cut are the same in each case. Fig. 6 shows good copper in "set," having a conductivity when drawn and annealed of 99.7%. Pnre metals when cast crystallize on cooling into irregular grains the size and distribution of which depend largely upon the size of casting and rate of cooling. When small quantities of impurities are present they form a matrix of what is probably an eutectic alloy of the metal and the impurities, in which the grains of pure metal are set. This is the case with the sample under discussion where the total impurities amount to about $^1/_{10}$%. Each of these grains is made up of smaller crystals, the cleavage being in different directions in grains. Fig. 7 shows a copper low enough in pitch to give trouble at the drawbench. It is the lowest of the series of points on Fig. 2 and runs 96.4% annealed. The change in

*A paper presented before the American Institute of Electrical Engineers, Nov. 20, 1903.

†Assistant to Superintendent, Raritan Copper Works, Perth Amboy, N. J.

structure is at once apparent and accounts for the brittleness developed.

When copper is rolled and drawn this granular structure is broken down, a fine fiber resulting. Fig. 8 shows a sample of trolley wire which has been heated over a gas-blast to a bright heat. It shows a partial return to the crystalline state, the duller surface in places having the same appearance as a hard-drawn sample as far as fiber is concerned. This explains the lowering of conductivity by overheating. The writer has never made measurements of the conductivity of cast copper, but understands from

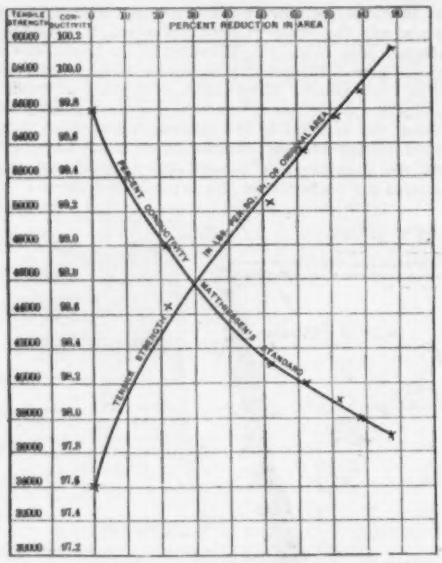


Fig. 3. Effect of Cold-Drawing Copper Wire.

work done at one of the wire-mills that it has been found to run about 3.5% lower than the annealed wire. This is entirely in accord with the data shown above. Copper that has been remelted in the foundry may run but 30 or 40%, due to the absorption of gases.

In cast copper we have a conductivity resulting from the combined conductivities of the pure copper grains and the impure matrix or cement. When this is rolled the structure is broken down and the complex shunt and series circuits rearranged to better advantage. When hard-drawn, the molecular freedom is restrained and more work has to be done in the necessary oscillation of an atom in passing a charge on to its neighbor. In annealing, the wire is brought to a temperature at which the cement is softened and all internal strain is equalized. In burning, crystalline growth is started and the metal reverts to the original condition.

EXAMINATION PAPERS FOR DIVISION IRRIGATION ENGINEERS, STATE OF COLORADO.

Colorado is one of the few Western States that attempts to supervise the distribution of water for irrigation. The State is divided into five grand sections, each in charge of a division engineer. These engineers are under the direction of a state engineer, which office is now filled by Prof. L. G. Carpenter, with Messrs. P. J. Preston and C. W. Wells as deputies.

In accordance with an act of the last legislature of Colorado, examination papers have been prepared for those wishing appointments as division engineers. We are indebted to Professor Carpenter for a set of the papers and application blanks. The following circular explains the general plan and scope of the examinations:

The Colorado Legislature of 1903 changed the title of Superintendent of Irrigation to Division Irrigation Engineer. The position is an administrative one, rather than professional.

The law provided that an examination should be given by the State Engineer. That all applicants who received a mark of 70% form an eligible list, from which the Governor makes the appointment for a term of two years. The Act provides that the candidate shall be marked on experience with a possible 40%, on a knowledge of the measurement of water, including field tests, 30%, and on laws and customs relative to irrigations and water rights in Colorado, 30%.

These papers include: (1) The form of application. (2) The questions on which the marking for experience is based. (3) Questions relating to the measurement of water, and laws and customs relative to irrigation and water rights.

It is said that the concrete questions in the latter case are a selection from those which came before the State Engineer in the course of a few days.

The application form contains numerous questions to be answered by the applicant, and also by two persons who must vouch for him. The latter

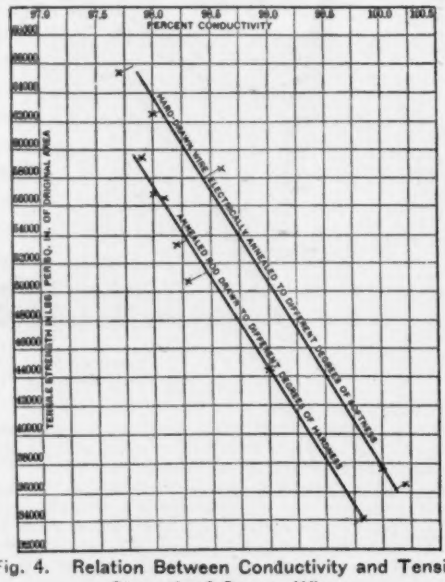

PERCENT CONDUCTIVITY
TENSILE STRENGTH IN LBS. PER SQ. IN. OF ORIGINAL AREA
HARD-DRAWN WIRE ELECTRICALLY ANNEALED TO DIFFERENT DEGREES OF SOFTNESS
ANNEALED ROD DRAWN TO DIFFERENT DEGREES OF HARDNESS

Fig. 4. Relation Between Conductivity and Tensile Strength of Copper Wire.

questions relate to the qualifications of the candidate, and to bonds of relationship and personal interests that might interfere with the just discharge of the duties of the office of division engineer.

The examination papers are in three parts: (1) A written examination, and (2) a field test on the measurement of water, and (3) questions on the laws and customs governing the distribution of water in Colorado. The questions in full are as follows:

MEASUREMENT OF WATER.

Part A.

(a) What is a cubic foot per second?

(b) What is a statutory inch? What is its value in cubic feet per second?

(c) The gate of a headgate is 4 ft. wide and is raised 6 ins. from the floor; the water stands 4 ft. deep on the floor in front of the gate; what is the amount of water discharged through the gate? Give the full computation.

(d) Describe how a weir should be placed and under what conditions and how the depth should be measured in order that the weir be reliable?

(e) Describe (1) where the rating flume of a ditch should be placed; (2) under what conditions; (3) why, and (4) what conditions to avoid and why?

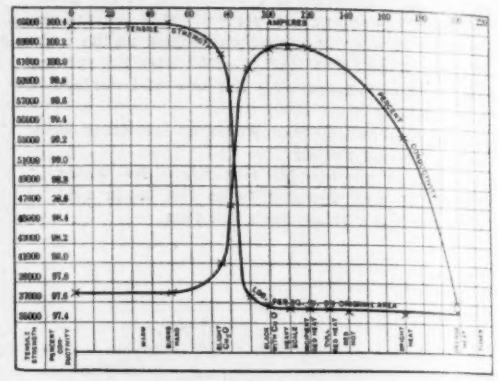


Fig. 5. Effect of Annealing at Different Temperatures; No. 12 B. & S. Copper Wire, Heated Electrically.

(f) How would you proceed to rate a ditch or canal? Give the process in full.

(g) A weir is 3 ft. long; the water is 6 ins. deep; compute the amount of water being discharged.

(h) A ditch takes out water in openings 9 ins. deep without pressure. The opening 10 ins. wide is then called 90 (ditch) ins.; how much water is discharged from such an opening, 10 ins. long? Are these inches greater or less than statutory?

(i) How much will a valve 40 ins. in diameter discharge if the head is 40 ft. on the center of the valve?

(j) If the depth over a wide-crested dam is 8 ins. and 100 ft. long, how much is the discharge?

PART B.—FIELD MEASUREMENTS.

(1) Each candidate will be expected to estimate the flow of water in two ditches:

(a) By eye.

(b) By float or other approximate means, without instruments.

(c) By current meter.

METHOD.—Make estimate (a) in writing, sign your name and hand to examiner, before (b). Likewise, complete (b), hand slips with your results to the examiner. Give the method in full with the calculations. (c) Make the measurement in full as you would in measuring a ditch. Give full calculations.

(2) Make the rating of a ditch, giving the process in full and making the rating curve and rating table.

LAWS AND CUSTOMS.

(1) What is the basis for water rights in Colorado? Does this apply to irrigation exclusively?

(2) What is the guide for the Engineer or Commissioner to follow in the distribution of water?

(3) If the stream is flucuating due to storms, melting snow, etc., and the earlier priorities are down the stream, how will you meet the practical problem of recognizing the priorities and still utilize all the water? Suppose a rise of water should occur in the river, how would you proceed?

(4) What are the duties and powers of a Division Irrigation Engineer? What authority does he have which is not given to the Commissioner?

(5) To what extent may a Commissioner interfere with the distribution of water from a ditch? What is the legal basis for your statement?

(6) A person owns two shares in a ditch and also owns an interest in a certain reservoir. One share, Share A, is used to irrigate a farm. Share B is unattached. The Court has specifically decided that Share B cannot be used for storage in the reservoir, but has never passed on Share A. The owner claims this holds only because of failure to appeal. He proposes to irrigate the farm with Share B, setting free Share A, and to store A. What is your decision and why?

Good Cast Copper.

"Low" Cast Copper.

"Burned" Trolley Wire.

FIGS. 6, 7 AND 8. MICRO-PHOTOGRAPHS OF COPPER (x 33).

(7) A ditch had an early appropriation of 60 cu. ft. per sec.; it habitually runs a large amount to the lower end and wastes back into the river. The ditch claims it can, because of its decree, while others claim that it is calling for water unnecessarily and should be refused the water which runs back into the river. Which is right and why?

(8) Suppose an early right is some distance down a sandy stream; likewise suppose that because of the absorption of the sand no water reaches the lower ditches. The lower ones claim that the water should be turned down; that even if it fails to reach them it serves to fill the sand, and when a rise comes it will be more apt to reach them. On the other hand, those above claim that this is waste and that the water should be turned where it does the most good. What is your decision and why?

(9) Two ditches which we may call A and B have headgates near each other, A being above B. They united in building a headgate, part of the gate being known as A's and part as B's. There is a stretch of canal owned in common and then at the end of the stretch each has its own gate. The priority of B is earlier than that of A. Canal A has bought some shares in B. The water represented by these shares is not, however, formally transferred to A. They claim the water should be measured in the common stretch of canal above the separate gates and they will run it, as they desire, into A or B. What is your decision and why?

LOCAL CONDITIONS.

(1) Give the limits of this division, the numbers of the water districts constituting it and their location by streams.

(2) Describe three districts of the division, their problems of administration and the questions they are apt to send up to the Division Engineer.

(3) Where is water storage used? What problem does it introduce into the administration and why?

(4) Suppose a ditch on the Platte has water stored in a reservoir on, say, Boulder Creek; how is that water to be delivered to the ditch below?

THE WILLIAMSBURG BRIDGE ACROSS THE EAST RIVER AT NEW YORK CITY.

(With two-page plate.)

The Williamsburg Bridge across the East River at New York city has been completed, and on Dec. 19 it will be opened for street traffic. This is the second suspension bridge to be built between New York and Brooklyn. Its only predecessor, the Brooklyn Bridge, was opened for traffic 20 years ago. In length of main span the new bridge exceeds the older one by only 5 ft., but its capacity for traffic is about three times as great, and in total length it exceeds the old bridge over a thousand feet. With one exception, the Forth cantilever bridge in Scotland of 1,710-ft. span, the Williamsburg Bridge is the longest span bridge in the world. It is the longest span suspension bridge ever constructed. Much greater suspension spans, it is true, have been designed, but no greater one has ever been built. Its peers among bridges of any type, either built or under construction, can be numbered on the fingers. These facts make it only just to the engineers who have created the work and to the community whose millions have been lavished in its accomplishment, that due measure of credit and honor be given them. There can be no better way of doing this than to describe in plain words the construction of the bridge.

Legislation and Preparatory Work.

The first definite step toward the construction of the Williamsburg Bridge was taken nearly nine years ago. It was prompted by the demand of the residents of Brooklyn for better means of transit across the East River to and from their daily work in New York. The Brooklyn Bridge had for a decade been inadequate to carry with any degree of comfort the crowds that night and morning sought passage across the river. Improvements had been made from time to time, but the travel grew faster than the accommodations could be increased, and it required no great foresight to see that the time was coming when further increases in the carrying capacity of the old bridge would be impracticable, while no limit was apparent in the growth to which the travel might attain. To the people of Brooklyn it seemed that their only resort lay in the construction of another bridge, and their mayor accordingly caused a bill to be introduced into the New York State Legislature which would make possible the building of such a structure. This bill became a law on May 27, 1895.

The act which passed the Legislature authorized the appointment of a commission composed of the mayors of New York and Brooklyn and six other members, three representing New York city and three representing the city of Brooklyn, and instructed this commission to construct a suspension bridge across the East River at a location which should bring its axis at or near Broadway in Brooklyn, and Grand St. in New York. In this statement of the provisions of the act two things require to be noted: first, the bridge was required to be a suspension bridge, and, second, its location was restricted to rather narrow limits. Another provision of the act, which requires mention, and which should be kept in mind, was that if any corporation possessed a valid charter for a bridge such as was contemplated by the act the commission might, with the consent of the mayors and comptrollers of the cities of New York and Brooklyn, purchase such charter, or, in default of mutual agreement on a purchase price, might institute condemnation proceedings to secure it.

Early in June, 1895, Mayor Schieren, of Brooklyn, and Mayor Strong, of New York, appointed, in obedience to the bridge act, six bridge commissioners. One of the first tasks of these commissioners was to appoint a chief engineer, and after considering many applicants Mr. Leffert L. Buck, M. Am. Soc. C. E., was chosen to the office. The appointment met with the unqualified approval of the engineering profession. Under Mr. Buck's energetic direction an organization was developed for carrying out the engineering work and affairs were rapidly whipped into shape to prepare for construction. Before much else could be done, however, the commission found itself under the necessity of purchasing the privilege of doing the work that it had been created to accomplish. To explain this peculiar circumstance it will be necessary to study events a few years previous to those we have been describing.

In 1891 a few astute and far-seeing men had obtained charters for two new bridges over the East River. These men did some work securing rights of way, and in performing other preliminary tasks incidental to the construction of great bridges like the ones proposed; then they did nothing more, times being hard and money scarce, until the act for a city bridge was urged by Mayor Schieren. Immediately thereupon, however, these gentlemen brought notice that the building of the proposed bridge would violate their moral rights and vested interests, and that they should be compelled to combat the act authorizing the construction unless said act guaranteed protection to their rights and interests. As they were strong men before the Legislature this was not an idle threat; no bill could be readily passed without their consent, and to secure this the bill must give permission for the old charters to be purchased. If the summary of the act already given be remembered, it will be seen that it provided for the purchase of existing valid charters if such were found. So much for the work in the Legislature.

The bridge act was passed and, as already stated, a commission was appointed to build the bridge. This commission endeavored at first to find a site which would not encroach on the old company's rights. The net had been too well spread, however, for escape in this manner. The law gave but limited choice in the location of the bridge; it provided further that any valid conflicting bridge rights should be paid for; in short, there was no possible way of escape which would not involve great delay, and, probably, ultimate failure. The logical conclusion seemed plain, and it was finally accepted by the commission, which agreed unanimously and with the consent of the mayors and comptrollers of New York and Brooklyn to purchase the charter of the East River Bridge Co., for the sum of $200,000. Altogether the deal was not a bad one; men still living remembered when a gentleman by the name of William M. Tweed and some friends of his were paid about $600,000 for similar rights to build the Brooklyn Bridge.

General Design.

The purchase of the East River Bridge Co.'s charter removed the last obstacle to the selection of a site and to the preparation of plans for the new bridge. To trace these labors step by step would occupy too much space and we shall, therefore, give at once the finally developed plan, and call attention briefly to some of its more general features. The final plan was completed by the engineer and adopted by the commission on Aug. 16, 1896; in May, 1897, a revised plan was substituted for the original plan. In planning the new bridge it was recognized that comparison was inevitable between it and the old Brooklyn Bridge, so long and so justly held by the public as the leading exponent of the suspension bridge builder's art. No radical change in construction was therefore felt to be warranted without good reason, and on the other hand, it was felt that no feature of the older structure should be copied unless time had proven that it could not be substantially improved upon.

The first step was to decide upon the capacity of the new bridge. This, it was considered, should be materially greater than that of the old bridge. After much deliberation it was decided to provide two carriageways each 20 ft. wide, four trolley car tracks, two elevated railway tracks, two footwalks and two bicycle paths. The widths adopted for these several thoroughfares were as follows:

Two footwalks, each 10 ft. 6 ins.	21 ft.
Two bicycle paths, each 7 ft.	14 "
Two elevated railway tracks	22 "
Four trolley tracks	40 "
Two roadways, each 20 ft.	40 "
Equivalent net width of single deck bridge	137 ft.
Width of Brooklyn Bridge (single deck structure)	73 "

With these dimensions adopted as a starting point the general design of the bridge was proceeded with.

Referring first to the location of the bridge, it was made an extension of Delancey St. in New York city. This location brings the Brooklyn end to land at a point about midway between South Fifth and South Sixth Sts., and about one block north of Broadway. At this point of crossing the land is about 20 ft. lower than at the ends of the Brooklyn Bridge. This made it necessary, with the condition that the grades should not be steeper than those on the Brooklyn Bridge, that the new bridge should be one-sixth longer; that all tracks and the roadways should be on the same level at the center of the river span, and that the minimum width of the bridge should be 118 ft. To meet these conditions it was decided to use four cables, with two trusses, the car tracks all being placed between the trusses and the roadways outside of them. It was also decided that the portions of the cables between the anchorages and the towers should carry no portion of the bridge load directly, but should act merely as back stays. This arrangement made possible the use of shorter cables and diminished their size and cost. To carry all the tracks and roadways through masonry towers would necessitate towers of enormous width and weight. Steel towers were, therefore, decided upon; their weight would be far smaller, thus making possible smaller foundations, and their construction would require much less time. Roughly speaking, masonry towers would require foundations twice as large, would cost five times as much, and would take three times as long to build. Another thing which influenced the selection of steel towers was that they could be more easily carried to greater height, and thus would decrease the size of the cables by permitting them to have a greater deflection. It was further decided that the stiffening trusses should extend from anchorage to anchorage. The selection of steel viaduct approaches was made because they were cheaper and more easily erected than masonry arches and would leave the right of way more free for public use.

The broad question of the choice of some other type of bridge than a suspension bridge was taken out of the hands of the commission and its engineer by the law which authorized the bridge. This law stated that the bridge to be built should be a suspension bridge. Why this was done it would be perhaps impossible to explain; at any rate there is reason to suppose that had the engineer's hands been left free he would have chosen a cantilever bridge. It is now idle to speculate upon this question, however; a suspension bridge was dictated and was, therefore, constructed.

It has been indicated in several places in the preceding description that the new bridge was made much larger than the old bridge. The extent of this increase in size may be most readily appreciated by studying the comparative cross-sections of the two bridges, and these are given in Fig. 1. To carry the comparison still further the accompanying tabular statement has been prepared (Table I.). The principal differences between the old and new bridges, aside from the

differences in dimensions and capacity, are the adoption of steel towers instead of masonry towers, and the relief of the shore cables from all direct load.

Masonry Substructure.

The masonry substructure of the Williamsburg Bridge comprises the anchorages, the steel tower foundations, the pedestals for the viaduct approaches and the short masonry approaches to the viaducts. Of these several structures only the first two named demand extended description. To preserve logical order, however, each class of work will be given attention in proportion to its importance.

DIAMOND DRILL BORINGS.

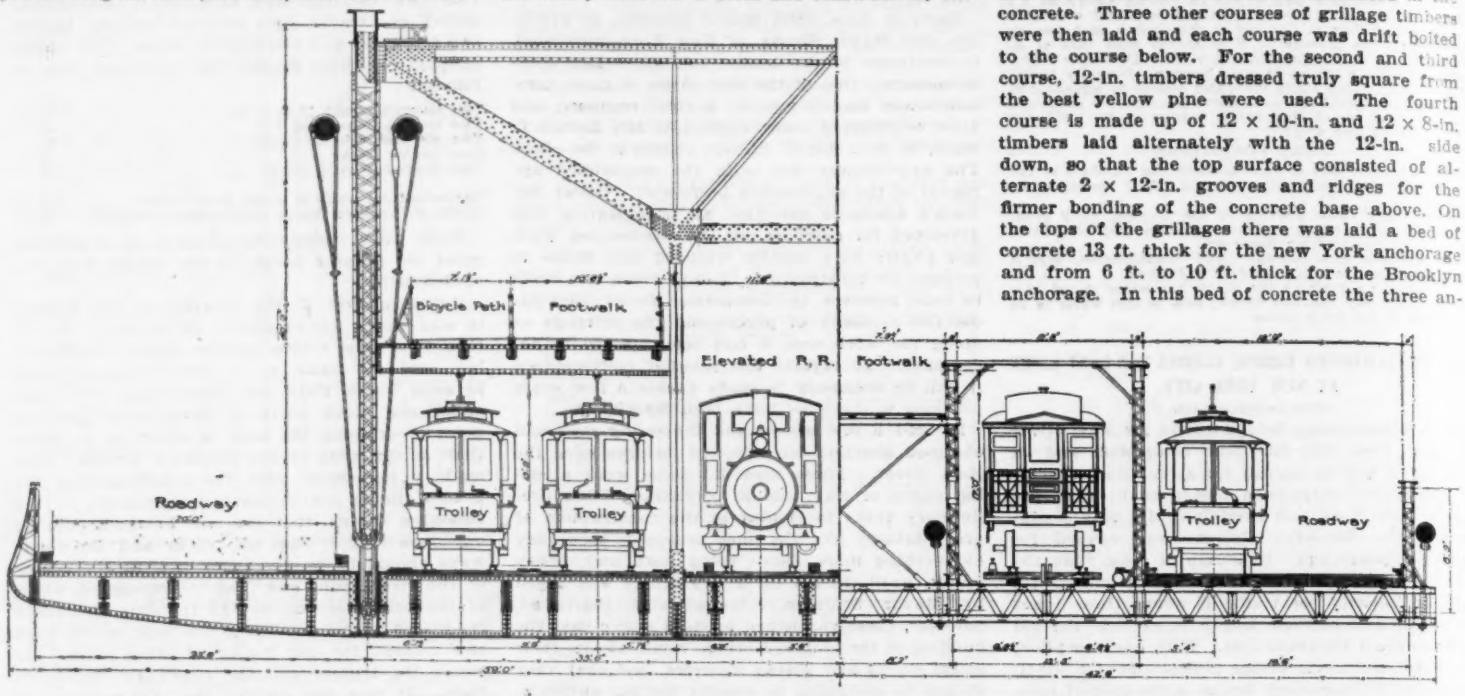
As a preliminary to founding the main towers an exploration of the character of the soil and the depth to solid rock was essential. This was at first attempted by driving steel pipe to the rock or to what appeared to be rock and then exploding a dynamite cartridge on the supposed rock surface. If the pipe failed to sink any further the testing party assumed that bed rock had been reached and on this supposition rock was indicated at 50 ft. below the water surface on the Manhattan side and at 75 ft. to 80 ft. on the Brooklyn side. Fortunately the engineer of the bridge was too wise to be satisfied with the results of soundings made in this manner and decided to have diamond drill borings made to such depths as would place beyond all doubt the true position and character of the underlying bed rock. A contract was therefore awarded to the New York & New Jersey Well Co., and the American Diamond Rock Drill Co. to bore 22 holes, on the sites of the tower foundations. The methods adopted for making these borings was somewhat unusual. Owing to the strong tideway and the heavy swell from passing vessels work from a floating platform was impossible. The plan resorted to was first to jet down and drive a pipe to bed rock by means of well boring machines. These machines were mounted on the bow and stern of a large scow. Heavy drive pipe was used and the start made with a 6-in. pipe. On reaching a boulder that could not be broken up or driven aside a hole was driven through it with the drop-tools, and a smaller pipe was inserted and driven down. This process was repeated until bed rock was assured. Solid rock once actually reached, a 2-in. pipe was sealed in it in such a manner as to make a sand-tight joint. The scow was then drawn back a few feet and a platform 8 × 10 ft. made of joists and plank was lowered over the pipe and clamped to it by bolts. This platform was guyed to anchors and to the scow and on it was mounted the diamond drilling outfit. The diamond drill holes were carried from 10 ft. to 20 ft. into the rock. As the result of the diamond drill borings the original pipe soundings were discovered to have been misleading. Instead of 50 ft. to bed rock on the Manhattan side the true depth was found to vary from 46.1 ft. to 68.3 ft.; and on the Brooklyn side the true depth ranged from 80 ft. to 105 ft. In only one out of 22 holes bored did the two sets of borings agree; in all others the supposed solid rock disclosed by the pipe soundings proved to be merely a boulder.

ANCHORAGES.

The two anchorages for the Williamsburg Bridge are nearly identical in form and construction, but the Brooklyn anchorage has somewhat greater lateral dimensions at the base. These differences are shown in the comparative table given above (Table I.). Since the two anchorages are similar in form and construction a description of one will answer for both.

In form the anchorages are wider than they are long and the rear or inshore ends are somewhat wider than the front or river ends. They are massive structures of concrete and stone masonry resting on solid timber grillages carried on piles. The foundation piles were driven at close intervals on the Manhattan side and were cut off to a uniform level 1 ft. above the bottom of the excavations. A bed of concrete was then placed over and around the pile tops; the thickness of this concrete was about 3 ft. The rear of the Brooklyn anchorage was also supported on piles and about 3 ft. of concrete placed over this. The balance of the foundation was formed by an 18-in. bed of concrete on the natural soil, which was a coarse sand and gravel.

Timbers 12 ins. square were bedded in the concrete transversely of the bridge about 5 ft. apart on centers and flush with the top of the concrete. This top surface was brought to exact level and on the first course of grillage timbers was laid in a bed of mortar, and drift bolted to the timbers embedded in the concrete. Three other courses of grillage timbers were then laid and each course was drift bolted to the course below. For the second and third course, 12-in. timbers dressed truly square from the best yellow pine were used. The fourth course is made up of 12 × 10-in. and 12 × 8-in. timbers laid alternately with the 12-in. side down, so that the top surface consisted of alternate 2 × 12-in. grooves and ridges for the firmer bonding of the concrete base above. On the tops of the grillages there was laid a bed of concrete 13 ft. thick for the new York anchorage and from 6 ft. to 10 ft. thick for the Brooklyn anchorage. In this bed of concrete the three anchorage girder chambers, one double chamber 50 × 40½ ft. for the inside cables and two single chambers each 25 × 40½ ft. for the two outside cables, were formed, and on it was erected the stone masonry. This masonry was solid except for the four curved anchor chain galleries and two interior wells. The outside finish consisted of a molded base of six-cut granite, a rock faced granite shaft and a molded cornice and coping of six-cut granite.



Half Cross-Section of Williamsburg Bridge. Half Cross-Section of Brooklyn Bridge.

FIG. 1. COMPARATIVE CROSS-SECTIONS OF THE WILLIAMSBURG AND BROOKLYN BRIDGES.

TABLE I.—Showing Comparative Dimensions of Williamsburg and Brooklyn Bridges, at New York City.

	Bridges	
Length:	Brooklyn.	Williamsburg.
Main span, c. to c. of towers	1,595' 6"	1,600' 0"
Land spans, tower—anchorage	930' 0"	596' 6"
Brooklyn approach	971' 0"	1,865' 0"
Manhattan approach	1,562' 6"	2,606' 2"
Total, of carriageway	5,989' 0"	7,264' 2"
Height:		
Clear, abv. m.h.w., at center	133' 0"	140' 4¾"
Same, 200' each side of center	.....	135' 0"
Above m. h. w. to center of cable at tower	272' 0"	332' 8½"
Above m. h. w. to roadway in center of span	138' 3"	145' 5¼"
Same, at center of tower	119' 3"	125' 7¾"
Of tower above roadway	159' 0"	210' 0"
Width of bridge	85' 0"	118' 0"
Grade of roadway in 100 ft.	3' 3"	3' 0"
Max. grade, roadway in 100 ft.	3' 9"	3' 4½"
Foundation below m. h. w.:		
Brooklyn	45' 0"	S.91.9', N.107.5'
Manhattan	78' 0"	S.66.0', N. 55.0'
Size of caissons: Brooklyn	168 × 102'	(2) 63 × 79'
Manhattan	172 × 102'	(2) 60 × 76'
Size of anchorages:		
At base—Brooklyn	129 × 119'	177 × 158'
At base—Manhattan	129 × 119'	173' 4½"×151' 9"
At top	117 × 104'	149' × 127' 5"
Diameter of cables	15⅝"	18⅜"
No. wires in each cable	5,296	7,700
Length of wire weighing 1 lb.	12'	10' 3"
Weight of one cable per lin.ft.	500 lbs.	770 lbs.
Total miles of wire in 4 cables	14,361	17,432
Versine at mean temperature	128'	178'
Ult. strength each cable, tons.	12,200	24,500
Permanent weight suspended:		
From main span cables, tons	6,780	13,740
From shore span cables, tons	7,900	0

The metal work within each anchorage comprises the anchors proper, the anchor chains and the girder supports for the anchor chains (Fig. 2). There are two anchor chains for each cable; each chain being made up of steel eye-bars placed side by side and linked together by a single pin at each joint. At the bottom each chain is attached to a separate cast-steel chain plate 10 ft. long and 4 ft. 9 ins. wide, and at the top the upper chain attaches to 18 and the lower to 19 strand shoes. The chain plates rest on grillages of 20-in. I-beams embedded in the concrete, eight beams for each anchor, and are held down by three sets of anchorage girders, one set for each outside cable and one set for the two inside cables. The anchorage girders are riveted steel plate girders arranged transversely and longitudinally so as to form a rigid framework rectangular in plan and of uniform depth or thickness. In the framework for the inside cables there are eight longitudinal and seven transverse girders varying from 66 ins. to 69 ins. deep. In each framework for the outside cables there are five longitudinal and seven transverse girders varying from 64 ins. to 68 ins. in depth. The masonry of the anchorage rests on these frameworks on all four sides of the chain galleries, and holds them in place by its weight. The effective weight of masonry above the anchorage girders is about 130,000 tons.

The two anchor chains for each cable are placed one above the other. The lower chain is supported at each joint by a cast steel knuckle plate set on the masonry floor of the chain gallery. Transverse plate girders extending across each gallery and supported on bearing stones carry the upper

chain at each joint. These girders vary in depth from 60 ins. at the bottom to 24 ins. at the top of the gallery. In all approximately 1,553 tons of metal were built into each anchorage, this total being made up as follows: Chains, 876 tons; girders, 474 tons; and castings, 203 tons.

The methods of work followed in constructing the anchorages do not call for extended mention. The work to be done was straightforward excavation, pile driving, concreting and stone masonry. The amounts of these classes of work and the restricted space in which the various tasks had to

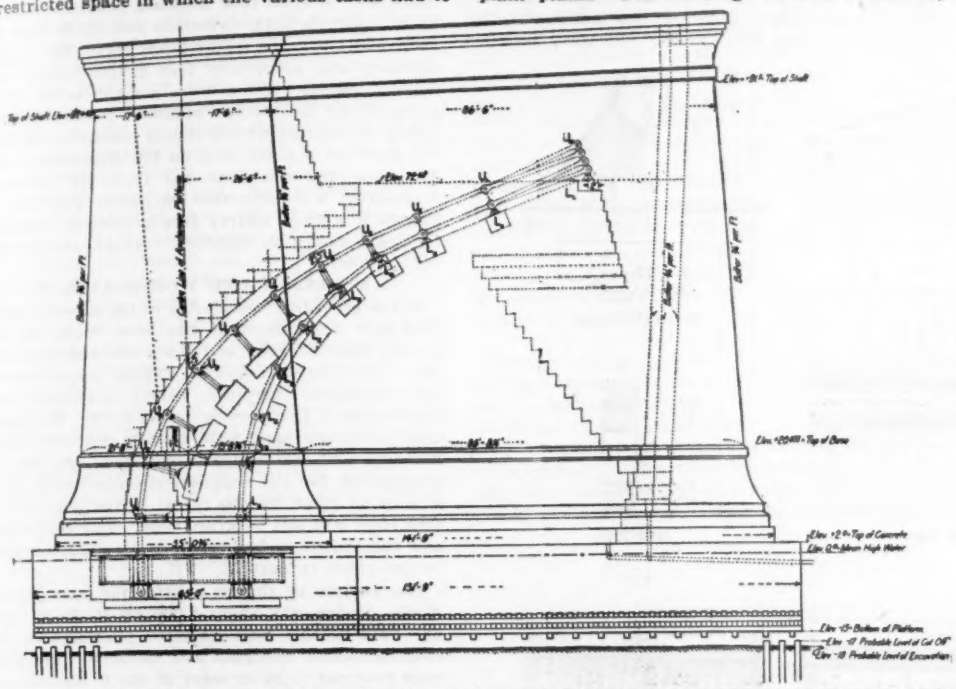


FIG. 2. SIDE ELEVATION OF NEW YORK ANCHORAGE, SHOWING ANCHOR CHAINS IN PLACE.

be performed made elaborate plants necessary and possible, and these were provided by the contractors. Separate contracts were let for the anchorages, that on the Brooklyn side being built by the Degnon-McLean Contracting Co., of New York, for $771,778, and that for the Manhattan side being built by Shanly & Ryan, of New York, for $797,770.

MAIN TOWER FOUNDATIONS.

Each main tower foundation consisted of two masonry piers, separately founded on timber caissons. These piers were identical in height and lateral dimensions above the water level, but below water they differed in size as did also the caissons on which they were founded. These facts make necessary a separate consideration of the two foundations and in some respects of the two parts of the same foundation. Before proceeding to this task, however, a statement of the dimensions above water is desirable. The piers for each tower were located in the same vertical plane at right angles to the bridge axis and 97.5 ft. apart c. to c., one on each side of the axis. The height of all piers above mean high water is 20 ft. to the coping level and 23 ft. to the tops of the pedestals. These pedestals each receive the bearing shoe of one tower leg and there are four for each pier and eight for each foundation. The pedestals on each pier are spaced 24 ft. apart transversely of the bridge and 40 ft. apart longitudinally of the bridge. The shafts of all piers above water level are rock-faced granite ashlar masonry. The cornice, coping and pedestals are six-cut granite.

BROOKLYN FOUNDATION.—The timber caissons for the Brooklyn tower foundation piers were each 63 x 79 ft. in lateral dimensions, the longer dimensions being parallel to the center line of the bridge. The height of the two caissons differed, as will be explained subsequently, but their general construction was identical. Each was surmounted by a cofferdam constructed in the same way for both, but differing in height. The general construction will be first considered.

The side walls of the caissons consist of two thicknesses of 12-in. square timbers set solid, one course vertical and the other course horizontal. The outside of these walls were sheathed by an inner course of 3-in. tongued and grooved plank laid diagonally and an outer course of 3-in. plain plank laid vertically. The bottom edges of all four sides were beveled on the inside and shod with a steel angle to form cutting edges. Seven feet in the clear above the cutting edges a solid floor was built to form a working chamber. This floor consisted of two courses of 12-in. square timbers set solid at right angles to each other and separated by two courses of 3-in. plank, one of which was tongued and grooved. The underside of the bottom course was sheeted with 3-in. plain plank. The working chamber formed by this floor and the sides of the caissons below it was divided into three sections by two transverse bulkheads 24 ins. thick of solid timber and the whole was strengthened by an interior bracing of struts and tie rods. Above the floor the caisson walls were braced together by a strong cob-house construction of horizontal 12-in. square timbers. Anchor rods extending upward into this bracing supported the bulkhead dividing the working chamber.

The cofferdam walls consisted of horizontal timbers laid solid against vertical inside studding and sheathed on the outside with two courses of 1¼-in. boards and one course of 3-in. tongued and grooved planking. The interior bracing between walls consisted of horizontal frames of transverse and longitudinal intersecting timbers; these frames were connected in both vertical planes by diagonals of 3 x 12-in. plank. The cofferdams were attached to the caissons with iron anchors.

The foregoing gives only the merest outline of the details of the caisson construction, but those desiring to consult details will find them published in Engineering News of May 27, 1897. Turning now to the differences in the two caissons, which were mentioned above, they can best be indicated in tabular form as follows:

Items.	Caissons—South.	Caissons—North.
Height in feet	39	53
Weight in tons	1,557	1,965
Draft in feet	15.3	17.9
Timber required in cu. ft.	64,000	82,000
Iron required in tons	77	90
Concrete above roof, cu. yds.	4,368	6,268
Concrete below roof, cu. yds.	1,435	1,566

It will be observed that the north caisson was considerably the larger. Both caissons were sunk in water about 58 ft. deep.

Both caissons were sunk by the pneumatic process and their sinking proceeded nearly simultaneously. To locate the caissons in the swift current two piers were built outward from the bulkhead line, one at the south of the downstream caisson and the other occupying the space between the downstream and upstream caissons. These piers acted as guides for directing the caissons into position. A third pier was then built parallel with the bulkhead line outside of the caissons. These piers formed the working platform. On the pier between the caissons the air-compressing plant was erected and on the others were located the derricks, concrete mixer and other working plant. Each caisson was equipped with six material shafts, a man shaft, a number of sand discharge pipes, and the usual air and water pipes.

The methods of work and the compressed air conditions were practically the same in both caissons, but the south caisson was sunk to somewhat less depth than the north, as shown by Table I. The bottom of the river, when reached, was found covered with about a foot of very offensive sewage sludge, and below this came sand, gravel and cobbles, with some boulders, overlying a bed of dry hard clay, which reached to bed rock. The sinking of the caissons through the softer materials was somewhat obstructed by boulders, but once the hard clay stratum was reached the work proceeded without incident. The clay was so hard and held the air so well that it was possible to carry the excavation at the center of the working chamber from 6 ft. to 8 ft. below the cutting edges. The excavated material was washed down and jetted out so far as possible, and the larger fragments were hoisted out of the material shafts. The sinkages were made intermittently, usually from 3 ft. to 6 ft. in one or two days. The maximum sinkage was 4 ft. in one day. The sinking was finally stopped at a depth somewhat above bed rock.

The maximum air pressure used was 38 lbs., and this was only for a short time; generally the pressures at greatest depth ran from 33 lbs. to 37 lbs. The pay and the length of shift of the pressure men were fixed by the depth and not by the degree of pressure. The terms agreed upon were as follows:

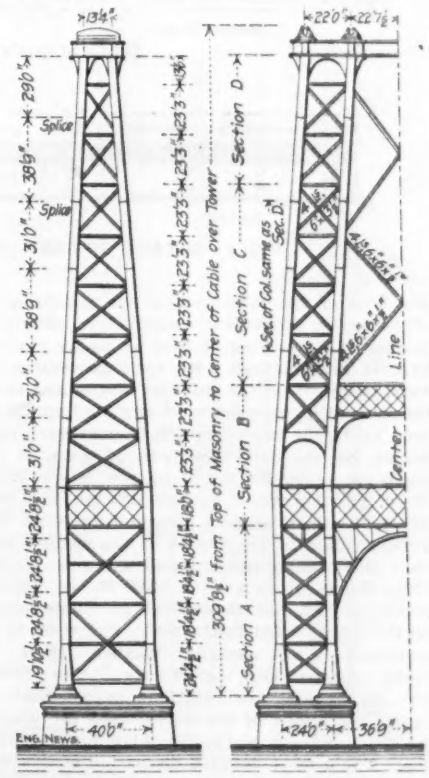


Fig. 3. Diagram Elevations of Main Towers.

Depth in feet.	Shift.	Wages.
All depths up to 55 ft.	8 hrs.	$2.50
Depths from 55 ft. to 70 ft.	6 "	2.75
" " 70 " " 80 "	2 "	3.00
" " 80 " " 90 "	1½"	3.25
" over 90 ft.	1½"	3.50

The working chambers were lighted by electricity, and all the compressed air was artificially cooled before being admitted into the working chamber. There was no serious trouble from caisson disease. The progress of the work was as follows:

Items.	Caissons—South.	Caissons—North.
Caisson begun	Aug. 12, 1897.	Oct. 20, 1897.
Caisson launched	Oct. 9, 1897.	Dec. 15, 1897.
Sunk to bottom	June 13, 1898.	Mar. 23, 1898.
Air pressure put on	Feb. 8, 1898.	July 5, 1898.
Bedrock encountered	April 2, 1898.	.....
Concreting chamber begun	June 7, 1898.	Oct. 24, 1898.
Concreting finished	June 21, 1898.	Nov. 4, 1898.
Masonry begun	Feb. 15, 1898.	July 26, 1898.
Masonry finished	October, 1898.	Dec. 13, 1898.

It will be observed from the preceding description that the greatest depth of work under air pressure was at the north caisson, where the excavation extended to 107.5 ft. below water level. As this is one of the greatest depths to which pneumatic foundation work has been carried a brief account of the compressed air conditions will be of interest. The highest point of bed rock under the north caisson was at the depth of 84.5 ft., and the lowest at the depth of 107.5 ft. The average depth of the natural rock surface within the caisson was 98.3 ft. The cutting edge of the caisson was stopped at a depth of 95 ft., so that the excavated rock surface covered only 42% of the area of the caisson; over the remaining 58% of area the excavation consisted in simply removing the overlying clay so as to lay clear the natural rock surface. No rock excavation was done, therefore, at the greatest depths, and in fact the amount of excavation of any kind which was done at depths exceeding 100 ft. was very small. Stated exactly, only 2 cu. yds. of material were taken out below 106 ft.; 21 cu. yds. below 104 ft.; 77 cu. yds. below 102 ft.; and 183 cu. yds. below 100 ft. The indicated air pressures exceeded those corresponding to the depths of the cutting edges until the caisson had reached a depth of 75 ft. From this depth to a depth of 90 ft. the indicated pressures and the theoretical pressures due to depth corresponded fairly well. Below 90 ft. the pressures were actually smaller than the depth theoretically called for. The foregoing statements are sufficient to establish the actual conditions of the compressed air work in the north caisson of the Brooklyn tower foundation. For a more detailed discussion of this work the reader should consult the article published in Engineering News of May 1, 1902. The contractor for the Brooklyn tower foundation was Colin McLean, and the contract price of the work was $485,082.

NEW YORK FOUNDATION.—The caissons for the New York tower foundations were each 60 ft. × 76 ft. in plan, and were set in the same vertical plane up and downstream with their longer dimension parallel to the bridge axis. They differed in construction from the caissons of the Brooklyn tower and also differed from each other. The borings at the foundation site disclosed bed rock, with an irregular surface, but dipping generally from north to south, with a depth below mean high water of from 45 ft. to 73 ft. The maximum depths of foundations were 66 ft. for the south caisson and 55 ft. for the north caisson. Overlying the rock there was a bed of sand interspersed with boulders at intervals just above the bed rock. Compared with the Brooklyn tower foundation, that on the New York side presented few difficulties. The chief feature of note is the fact that for caissons sunk to nearly the same depth and identical in lateral dimensions and load two different constructions were adopted.

The south caisson was 27 ft. high from cutting edge to cofferdam connection. The side walls consisted of 12 × 12-in. timbers laid solid against vertical inside studding. At the bottoms of the side walls a cutting edge 2 ft. deep was formed by a steel plate braced with inside plate brackets. Eight feet above the cutting edge in the clear came the roof of the working chamber built of four courses of 12 × 12-in. timbers laid solid. The working chamber was divided into three sections by longitudinal bulkheads, 24 ins. thick, of 12 × 12-in. timbers laid solid. These bulkheads were braced apart and to the side walls by a system of horizontal struts, diagonal braces and steel tie rods. Above the chamber roof the side walls were braced together by four transverse and three longitudinal intersecting Howe trusses. The transverse trusses are 17 ft. deep, and the longitudinal trusses are 19 ft. 8 ins. deep, so that the chords of the latter were outside those of the former at intersections. Between these intersecting trusses there is a cob-house bracing of 12 × 12-in. timbers reaching from wall to wall. It should be noted also that the bottom chords of the longitudinal trusses come below the chamber roof, while those of the transverse trusses are on the plane of the bottom layer of roofing timbers.

The north caisson was 19 ft. high from cutting edge to the junction of the cofferdam. The construction of the side walls and cutting edges was practically the same as in the south caisson. The working chamber roof consisted of four courses of 12 × 12-in. timbers separated at the middle by two courses of 2-in. plank, all laid solid. Above the roof the transverse bracing consisted of eight steel trusses, the bottom chords of which were embedded in the second course of roof timbering. Longitudinally the bracing consisted of four lines of 12 × 12-in. timbers set one above the other, and blocked 12 ins. apart at intersections with the steel trusses. The working chamber was divided into three sections by two solid timber bulkheads and was braced with horizontal struts, diagonals and tie rods.

The sinking of the caissons calls for very little mention, it being straightforward pneumatic work at no great depth. No cofferdams were used, the masonry being built upward as fast as the caissons descended. The contractor for the foundations was P. H. Flynn, of New York city, and the contract price of the work was $373,462.

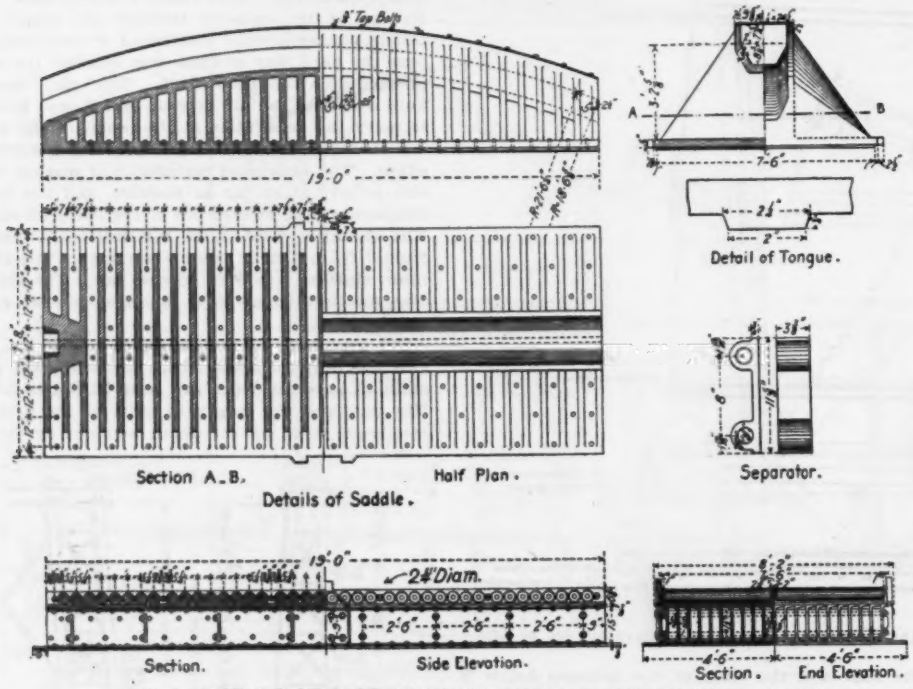


FIG. 4. DETAILS OF CAST STEEL SADDLES FOR SUSPENSION CABLES.

MINOR FOUNDATIONS.

Besides the anchorages and the main tower foundations already described, the masonry substructure includes the foundations for the shore span towers, the retaining walls and masonry piers of the earth-fill approach and the column footings for the viaduct approaches. The shore span towers called for the largest individual foundations outside of the main towers and anchorages. The four shore span tower piers were each 38 ft. square and consisted of a timber grillage on piles covered with a cap of concrete about 5 ft. thick. On this concrete cap were laid three courses of masonry each 2 ft. thick and each stepped in 6 ins. from the course below. On this masonry there were erected four masonry pedestals spaced 18 ft. apart in both directions and 12 ft. high to receive the bottoms of the tower legs. The facing masonry was all quarry face granite except the coping courses, which were six-cut work. The pedestals for the viaduct approach tower legs consisted of concrete with a coping course and pedestal stone of granite, and on the Manhattan side for some distance from the river the concrete foundation was supported on piers. The retaining walls were of quarry face granite on concrete footings, and with cornices, copings, etc., of six cut granite.

MATERIALS AND WORKMANSHIP.

In the preceding description of the masonry substructure little mention has been made of the quality and character of the materials used and of the workmanship required. These items deserve brief mention, therefore, before concluding the description of this portion of the work. The principal materials used were timber, concrete, stone masonry and cast and wrought steel. As the requirements for the foundation metal work were similar to those for the metal in the superstructure they will not be given here. The concreting and the timber and masonry work will, however, be described in outline.

The amount of timber used in the construction of the bridge was about 8,000,000 ft. B. M., and the bulk of this was used for piles and in the construction of grillages and caissons. The piles were required to be at least 10 ins. in diameter at the smaller end and 14 ins. in diameter at point of cut-off. All piles were of yellow pine sound and free from shakes and knots. For grillages and caissons, long leaf yellow pine of the highest quality was required. This was all sawed timber and much of it was also dressed on all sides or on two opposite sides.

All concrete consisted of six parts of broken stone to three parts of mortar, composed of 375 lbs. of Portland cement to 8½ cu. ft. of sand. The cement was required to be of such quality that a seven-day neat test developed a strength of 350 lbs. per sq. in., and a seven-day one to two mortar test developed a strength of 150 lbs. per sq. in. At least 90% of the cement was required to pass a 10,000 mesh seive. The sand was required to be clean, sharp and free from mica; for masonry it had to pass a ¼-in. square mesh screen. The broken stone was required to be hard limestone or trap and screened of all pieces larger than 2 ins. and smaller than ¼-in. The cement and sand had

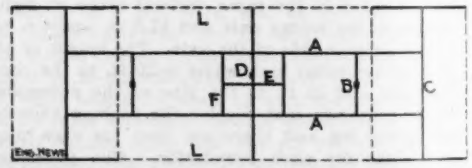


Fig. 5. Diagram Showing Girder System Supporting Suspended Span at Towers.

to be mixed dry and then wet, and the broken stone had to be added to the mortar and the two mixed by machine. The concrete was required to be deposited and rammed in layers not over 1 ft. thick.

The stone masonry work specifications called in general for a very high character of ashlar work. All facing stones were required to be of granite, quarry faced for the shafts and bodies and six-cut work for the base, cornice, coping and trim generally. The backing was permitted to be limestone of good quality.

Steel Framework Superstructure.

For convenience the bridge superstructure is assumed to comprise all work above the masonry foundations. These portions of the bridge com-

prise, first, the steel framework structure, including towers, shore spans, stiffening span and viaduct approaches, and second, the steel wire cables which carry the main suspension span from the towers. The steel framework structure and the suspension cable system will be considered separately, and in the order named.

MAIN TOWERS.

The main towers which carry the suspension cables each consist of eight columns strongly braced together laterally in all directions. At about the floor level they are provided with a system of girders to support the ends of the end spans as well as the ends of the suspended structure of the main span. At the tops of the towers there is another system of girders, on which rest the saddles with their friction rollers. The outline elevations, Fig. 3, show clearly the general arrangement of the tower legs and their bracing. Only a few of the details need be noted.

The columns rest on cast steel pedestals 11 ft. square, connected to the masonry by 2½-in. anchor bolts. At the bottoms the columns are about 84 × 68 ins., and above the flare they are about 48 × 32 ins. in cross-section. At the bend in the columns, which occurs at about floor level, a wedge-shaped angle block or shim of cast steel provides for the change in direction instead of a beveled connection. Above the bend the columns are about 48 × 34 ins. in cross-section. The height of each tower to the bottom of the saddle platform from the masonry is 297 ft. The platform is composed of intersecting plate girders about 86 ins. deep floored over with steel plate. On this platform rest the four cable saddles, constructed as shown by Fig. 4. These saddles are steel castings and weigh about 36 tons each. The height from the masonry to the center of the cables over these saddles is 309 ft. 8½ ins. The weight of the steel in each tower is about 3,048 tons.

The erection of the tower steelwork was accomplished by means of the end span falseworks and travelers to the level of the top of the portal bracing above the main floor platform. On this bracing there was then erected a timber tower 32 ft. square and 151 ft. high. Derricks on the top of this tower handled the steel and the tower was carried up story by story. The final operation was the placing of the saddles and these were raised one at a time by means of gallows frames on the top of the tower.

INTERMEDIATE TOWERS.

The shore spans of the bridge are not suspended from the main cables, but are supported by the anchorages and main towers and by intermediate towers between. These intermediate towers each consists of two separate towers of four columns, connected together at the top by cross girders and arched bracing. The feet of the columns rest on cast steel pedestals anchor bolted to the masonry footings, and their tops connect with and are surmounted by the girder platform before mentioned. On this platform over each tower there is placed a cast steel pin bearing resting on expansion rollers. The height of the towers from the masonry to the center of the pin bearing is 96 ft. 3¾ ins. These towers were erected by means of the falseworks and travelers employed in erecting the end spans.

END SPANS.

The end spans comprise those portions of the bridge between the main tower and the anchorage on each side of the river, and there are four of them, two on each shore. As the construction is identical on both shores a description of one set of spans suffices for both sets. Starting from the anchorage the first span is 296 ft. 4⅞ ins. long from the pin center in the anchorage to the pin center of the intermediate tower bearing, but it is continuous over the tower for three panel lengths further or for 59 ft. 3¾ ins. This span was termed the cantilever span. From its cantilever end to the main tower the distance is 217 ft. 5¾ ins., and is spanned by another structure known as the connecting span. These spans each consist of two trusses spaced 67 ft. apart, c. to c., and having a depth of 40 ft. between centers of gravity of chords. The trusses are triple intersection latticed trusses. The connecting span is connected to the cantilever by a bottom chord pin connection and the top chord is discontinuous except for a device for transferring wind pressure.

At each panel point there is a plate girder floor beam between opposite bottom chords. The tops of these floor beams are flush with the tops of the chords and they are 4 ft. 3½ ins. deep. These floor beams are extended outside of the trusses on each side of the bridge to form the cantilever roadway beams. The arrangement is exactly similar to that shown by Fig. 1. This same drawing also shows the transverse overhead trusses which connect the main trusses at panel points, and provide intermediate supports for the floor beams and for the inner ends of the upper deck girders. It only remains to be noticed that there is a top and bottom single intersection lateral system between the trusses, and that every third pair of roadway beams has X-bracing in the plane of the top flanges. All connections are riveted.

The erection of the end spans was accomplished by means of a continuous timber falsework carrying travelers and derricks. The work was fully described in Engineering News of March 8, 1900.

SUSPENDED SPAN.

The suspended span consists of two parallel trusses with the floor systems and transverse bracing shown by Fig. 1. The trusses are 1,600 ft. long, between centers of main towers where they are supported on rocker bents, but they project, however, 23½ ft. beyond the rocker connections, so as to extend through the towers and connect with the adjacent shore spans by means of bottom chord pins and top chord riveted joints. The trusses are triple intersection latticed trusses, and they are suspended at each panel point from the main cables as is described later. There are 78 panels between towers, each being 19 ft. 11 ins. long on the bottom chord and slightly longer on the top chord. The panels inside the towers are longer than the others and are of irregular construction. The top and bottom chords are respectively 30 ins. and 25 ins. wide and 27 ins. deep. There are

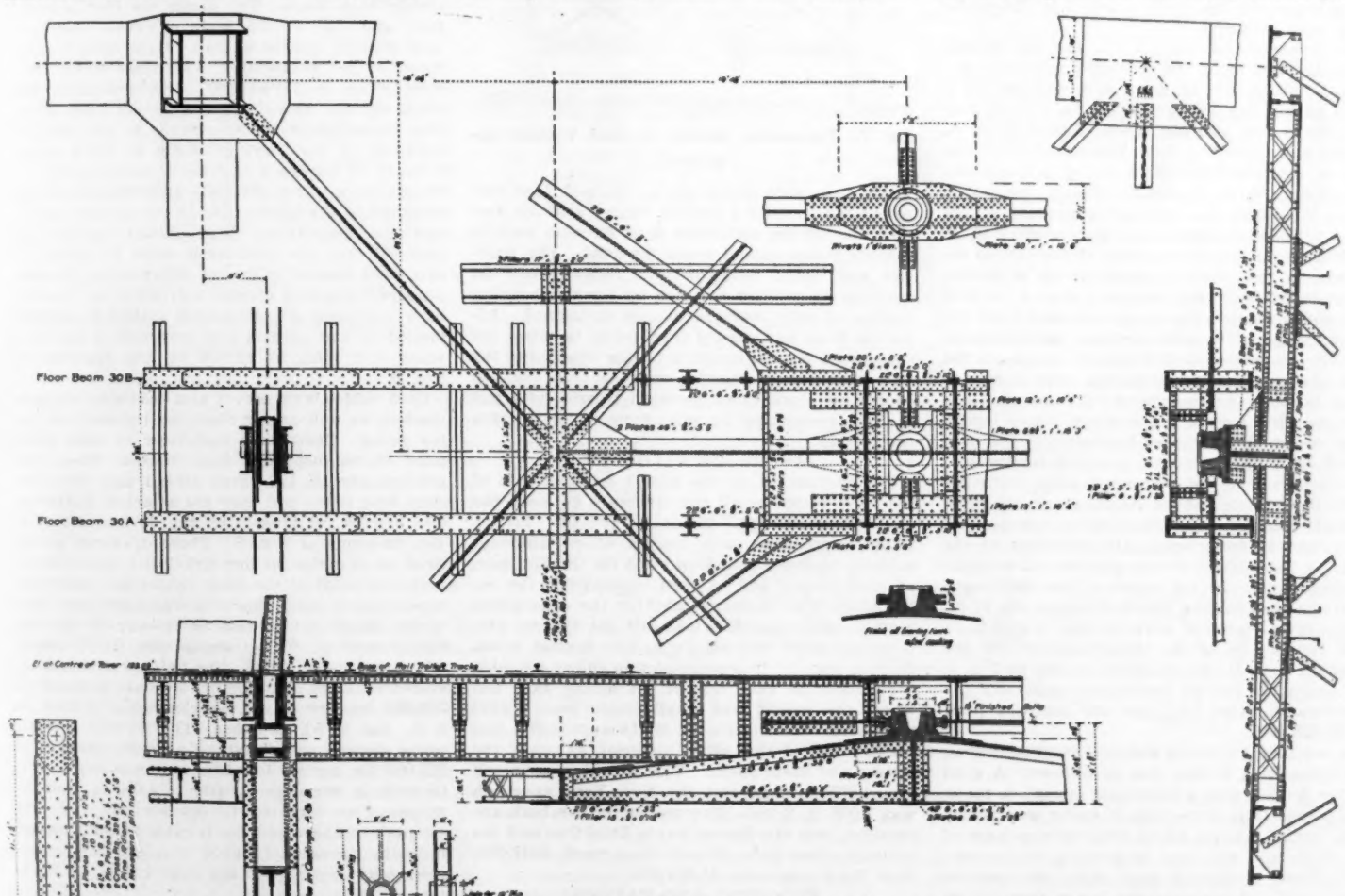


FIG. 6. DETAILS OF ROCKER SUPPORT OF SUSPENDED SPAN AT TOWERS.

X-brace lateral diagonals reaching across three panels in the top and bottom chord planes, and every third panel of the roadway floor beams is braced by a pair of lateral diagonals. In general the cross-section of the span is substantially the same as that of the shore spans and is clearly shown by Fig. 1.

The bottom chords of the stiffening trusses have a rise of nearly 19.9 ft. at the center, and, for 338.47 ft. on each side of the center, are cambered to a curve of about 11,107 ft. radius. The ends are cambered to curves of 160,000 ft. radius. The radius of curvature of the top chords at the center is about 78,289½ ft. At each end of the trusses two panels of the top chord are offset horizontally toward the bridge axis about 3 ft. to make them clear the inclined tower columns. The adjacent ends of the posts and the regular top chord sections are widened and stiffened to provide for this change in the general plan.

In each tower there is, just below the roadway level, besides the main lattice girders which are in the faces of the tower, a system of longitudinal and transverse girders which are between the former and are concealed by them. The main transverse girders, A, A, in the accompanying diagram, Fig. 5, are web connected to two longitudinal girders, B, B, in the planes of the stiffening trusses, and the stiffening trusses are connected to the girders, B, B, by vertical rocker posts about 11 ft. long, which have at each end jaw plates to engage 12-in. pins transverse to the bridge axis. These pins take bearing in steel castings, one of which is bolted between web plates projecting below the bottom chord of the stiffening truss and the other is bolted to the center of the web of girder B.

The transverse girders, A, A, and the outside lattice girders, L, L, are connected together by a truss, D, about 18½ ft. deep on centers, which is in the axis of the bridge and has its top and bottom chords just clearing those of girders, A, A, outside, and riveted to them. The top chord of this truss is intersected in the center by a transverse plate-girder, E, in the center line of the tower. Girder E is 36¾ ft. long and supported at the ends by the short longitudinal plate girders, F, F, which also support the middles of the lateral diagonals. A steel casting seated on top of girders D and E, at their intersection, forms a vertical pivot which receives the lateral stresses from the suspended span. The components of the horizontal stresses are transmitted from the pivot to the tower bracing, and the suspended span is free to deflect laterally on the pivots. In the plan-diagram only the members are shown which belong to the tower, the members belonging to the suspended span being omitted to avoid confusion.

At each end of the suspended span there are double floor beams, about 7½ ft. apart and symmetrical with the center lines of the towers, and these pairs of floor beams are connected at the center by pairs of transverse girders and horizontal diaphragms. In the center of the diaphragm is bolted a steel casting bored to engage the 17-in. vertical pivot on top of tower girders D and E.

The full details of the rocker support for the suspended span at the towers are shown by Fig. 6. The contractor for the suspended span was the Pennsylvania Steel Co., and the contract price was $1,123,400.

The method of erecting the steel suspended span of Williamsburg Bridge was as follows: A steel stiff leg derrick with a boom long enough to reach three panels from river face of tower was placed on the portal bracing above the roadway level of each tower and was used in hoisting all the material of the suspended span from the material tracks built out between the tower foundations and around the northerly stone pier.

The floor of the portion of the steel suspended span in the towers was first put in place and two powerful hoisting engines placed thereon at each tower. Then, by means of the steel derrick previously described, three panels of flooring, including the bottom chords of trusses of the suspended span adjoining each tower, were put in place. Upon this flooring in front of each tower a steel traveler, weighing about 80 tons, was erected. This traveler spanned the width transversely between the two main trusses and extended three panels longitudinally, and was supported on a tram rail laid along the outside trolley stringer on each side. On top of the traveler the steel stiff leg derrick was set up with the main boom extending from the river end with reach enough to place the chord sections averaging three panels in length and weighing a maximum of 28 tons.

The bottom chord sections were first put in place and attached to the suspenders from main cables, and then the floor beams and stringers were placed and track for the traveler laid. The traveler was then moved forward to erect the next section of floor. This operation was repeated until the bottom chords and flooring of the

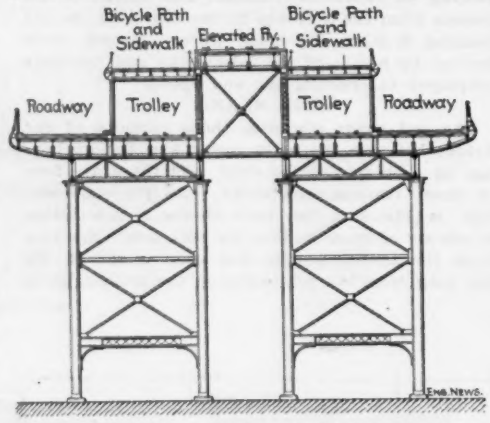


Fig. 7. Transverse Section of Steel Viaduct Approach.

whole span were put in place. On each land corner of the traveler a smaller timber stiff leg derrick was set up, and these derricks were used in placing stringers and small material. The traveler was moved backward and forward and the derricks on traveler operated by the two hoisting engines at each tower previously mentioned. After the floor was erected from tower to tower the suspenders were adjusted to proper length and the web members of trusses were set up, the top chords and transverse overhead trusses were put in place, completing the work from center towards the towers.

APPROACH VIADUCTS.

The approaches to the bridge on each side of the river comprise all the structure between the anchorages and the terminals of the bridge. These approaches each consist of embankment between masonry retaining walls for the first part of their length and of steel viaduct for the remainder. The masonry parts of the approaches have already been described and the viaduct portions are quite well shown by the typical cross-section, Fig. 7. This cross-section shows a double bent tower on each side of the bridge axis, but where the height was small single bent towers were used. The steel work of the approaches was constructed of the same material as were the towers and main spans. The Brooklyn approach was 1,865 ft. long and the New York approach was 2,606 ft. 2 ins. The contractor for both approaches was the Pennsylvania Steel Co., and the contract prices were: Brooklyn approach, $947,000; New York approach, $1,464,000.

FLOORING AND PAVING.

The flooring and paving of the foot walks, bicycle paths and roadways call for brief mention only. Considering first the roadways, it should be noted that the flooring and paving of the approaches differed from that of the main and end spans. For the first mentioned portions of the bridge the roadways consist of stone block on a concrete base laid on buckle plates for the viaduct and on concrete on the earth fill elsewhere. For the main and suspended spans a creo-resinate wood block pavement was laid on a solid floor of steel channels set edge to edge with flanges down and close joints. The foot walks are covered with corrugated plates covered with concrete having a rock asphalt mastic wearing surface on top.

MATERIALS AND WORKMANSHIP.

Acid open-hearth steel made by the pig and ore process was used for all parts of the steel framework. The chemical and physical requirements differed slightly for the steel for the end spans and towers and for the steel for the suspended span. The requirements in each case are shown by tables II. and III. The requirements for workmanship were substantially the same for all the steel work. They were generally such as are required for first-class bridge work and only a few call for specific mention. All material less than ¾-in. thick was required to be punched and reamed, and all over this thickness was required to be drilled assembled. No hand riveting was allowed except where machine riveting was impracticable.

Main Cables and Suspenders.

As will be recalled from the preceding description, the weight of the main span of the bridge is carried directly by the main suspension cables, but the spans between the towers and the anchorages are supported independently of the cables and these portions of the cables are, therefore, simply back stays. The cables are four in number and are at the same elevation; they are only slightly cradled in plan. Each cable is composed of No. 6 Roebling Wire Gage (0.192 ins.) steel wires in 37 strands, each containing 208 wires and the whole cable containing 7,696 wires. The arrangement of the strands in the cable is indicated by the drawings of Fig. 8. Each strand is made by looping a continuous wire around two strand shoes, which are horse-shoe shaped castings attached to the upper ends of the anchor chains, and these strands are then bunched together and clamped into one cylindrical cable by means of cast steel clamps or sleeves which carry the suspenders. Between clamps the cables are covered by a wrapping of cotton duck soaked in oxidized linseed oil and varnish gum composition and by a sheet iron shell, as shown by the drawings of Fig. 9.

Each cable clamp serves as a saddle for the suspenders as well as for clamping together the cable wires. There is a suspender at each panel point of the suspended span trusses. These suspenders are 1¾-in., seven strand and wire core steel wire ropes and they are attached to the cables and to the trusses by the devices shown in the drawings of Fig. 8. These drawings are so clear as to make further description unnecessary.

The material of the main cables and suspender ropes is steel wire. This wire was made from steel which should not contain to exceed: Phosphorus, 0.04%; sulphur, 0.03%; manganese, 0.5%; silicon, 0.1%, and copper, 0.02%. The finished wire was required to have a minimum ultimate strength of 200,000 lbs. per sq. in., an elongation of 2½% in 5 ft., and of 5% in 8 ins. The wire as actually made showed under test an ultimate strength of 225,000 lbs. per sq. in. The wire was required to be made in minimum lengths of 4,000 ft., and the splices were required to develop 95% of the strength of the wire. Each cable as built has an ultimate strength of 24,500 tons and the permanent load carried by the four cables is 13,740 tons.

The construction of the main cables was a task of special interest and the means adopted are deserving of particular mention. The first work to be done was the building of working platforms.

TABLE II.—Chemical Composition of Steel for Towers and Spans of Williamsburg Bridge.

Element.	Spans, Towers and end.	Spans, Suspended.
Phosphorus	0.08%	0.06%
Sulphur	0.03%	0.04%
Manganese	0.5%	0.8%
Silicon	0.1%	0.35%

TABLE III.—Physical Requirements for Steel for Towers and Spans of Williamsburg Bridge.

	Towers and end spans			Suspended span		
	Angles, plates and anchor bolts.	Pins and rollers.	Rivets.	Shapes and mill plates.	Sheared plates and pins.	Rivets.
Ultimate pounds per sq. in.	60,000 to 68,000	min. 68,000	47,000 to 56,000	60,000 to 68,000	60,000 to 68,000	54,000 to 60,000
Minimum elastic limit, sq. in.	33,000	35,000	30,000	Not less than one-half of above.		
Minimum elongation, per cent.	20	17	25	22	20	25
Red. area	..	..	..	44	44	50

These consisted of two suspended structures, one on each side of the bridge axis, about 67 ft. apart and parallel in plan. In elevation these platforms were parallel to the vertical profile of the completed cables. Between towers each platform was a double deck structure, the upper deck being about 4 ft. below the position of the strands during their formation, and the lower deck being just below the final position of the strands in the finished cable. The two platforms were connected at intervals by cross-walks and their general appearance is very clearly shown by the view, Fig. 10. In character and construction each platform was a suspension bridge of considerable dimensions and capacity. They were described in detail in Engineering News of Oct. 9, 1902.

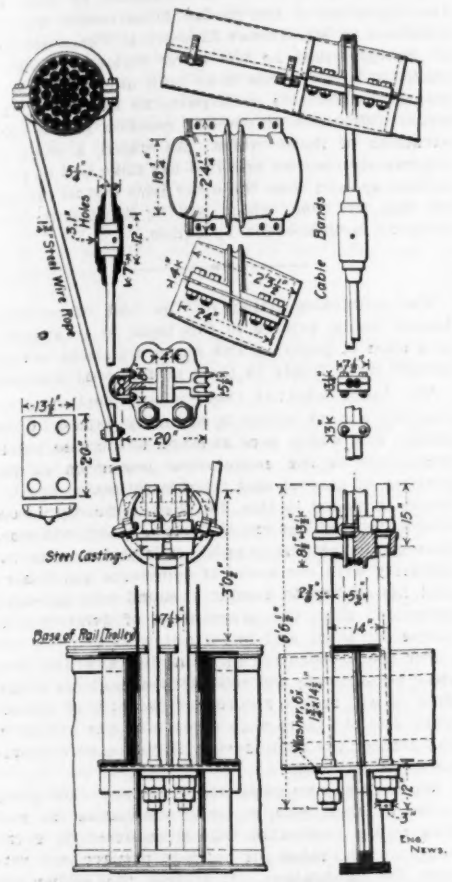


Fig. 8. Details of Cable Bands and Suspender Connections at Trusses.

The cable wire was shipped to the bridge site on reels, each of which contained about 80,000 ft. of wire, weighing about four tons, the wires averaging about 3,500 ft. in length, completely spliced to form one continuous wire. In constructing the cables the first task was to form the strands and the second was to lay the strands into the cable. Each strand was formed complete above the level of the cable and was lowered into position only when completely formed.

Considering first the strand making, a timber frame was set on each anchorage to the rear of and in line with each cable. In each of these frames four reels of wire were set tandem. To carry the wires from these reels across the bridge a wire ropeway was installed on each side of the bridge axis. Each ropeway consisted of an endless rope, passing around horizontal sheaves on the anchorages and over the towers on guide sheaves. One part of this ropeway was directly above each cable. Sheaves were attached to the endless rope at diametrically opposite points. In starting a strand the endless rope was pulled around until one sheave was at each anchorage. The end of the wire from a reel at each anchorage was fastened to a strand shoe secured in a horizontal plane to a vertical "leg," keyed to the anchor chain about 20 ins. from its extremity. Enough of this wire was then unwound from the reel to make a bight and this bight was thrown around the traveling sheave on the endless rope. This was done at each anchorage. The endless rope was then set in motion and the sheaves traveled across the bridge in opposite directions, one over the line of each cable and each carrying a bight of wire and thus laying two wires in each strand. When the sheaves reached the anchorages opposite their starting points the bights of wire were removed from them and looped around the proper strand shoes, and a bight of wire from another reel was placed over the carrying sheave and hauled to the opposite anchorage, thus adding two wires to the second strand of each cable. In this manner the operations were repeated until the 208 wires in each of the two strands of a cable were in place, a maximum of eight strands being strung at one time. As soon as one reel was empty the rear end of its wire was spliced to the forward end of the wire on another reel and the work proceeded. It should be noted that there were two of these ropeways, one on each side of the bridge axis. Before the stringing of any strand was commenced the guide wire was put in place and the first 6 or 8 wires of the strand were adjusted parallel thereto; the guide wire was then removed and the remaining wires were strung parallel to those already adjusted. The strand when completed was detached from its temporary fastenings at the ends, drawn clear of its support by a ratchet jack and slacked off toward the tower far enough to admit of its permanent connection to the anchor chains. It was also lifted clear of the supporting sheaves over the saddles on the towers and lowered into the saddle by means of screw jacks and then adjusted to its proper position in the cable. When all the strands of a cable had been laid the temporary strand seizings were removed and the cable was squeezed into its cylindrical form and the cable bands clamped in place, and the cable was wrapped and armored as previously described. The contractors for the cable wire and for the construction of the cable were The John A. Roebling's Sons Co., of Trenton, N. J., and the contract price was $1,398,000.

Accidents.

Only one serious accident occurred in constructing the bridge. On Nov. 10, 1902, a fire burned the contractors' shanties and other combustible material stored at the top of the New York tower and did considerable damage to the adjacent cable wires. At the time of the fire the cables had been completed except for the wrapping and armoring, which had just been commenced. An examination of the injuries showed that about 500 wires had been injured by heat in the two cables on the southern side of the bridge; 200 of the injured wires were in the outside cable and the injury was confined to the top of the cable over the saddle, and 300 were in the inside cable. A commission of engineers employed to determine the amount of injury done and to suggest methods of repairing it, reported after making careful tests of the injured wires that one cable had had its original strength reduced 2.5% and the other cable 6.5%. As the wire actually used in making the cables had been 12% stronger than the specified strength of 200,000 lbs. per sq. in., however, it was pointed out that the injured cables were stronger than the specified requirements.

To repair the injury it was recommended that all wires where possible should have their injured parts cut out and replaced by new wire spliced in; that all the other wires should be tightened, and that additional wires be put in over the saddles and connected to the cable by bands designed to clamp the cable. These repairs, it was calculated, would leave the cables only ½ of 1% and 2% weaker than they were originally, and from 8% to 10% stronger than the specified requirements. The repairs were made according to these recommendations.

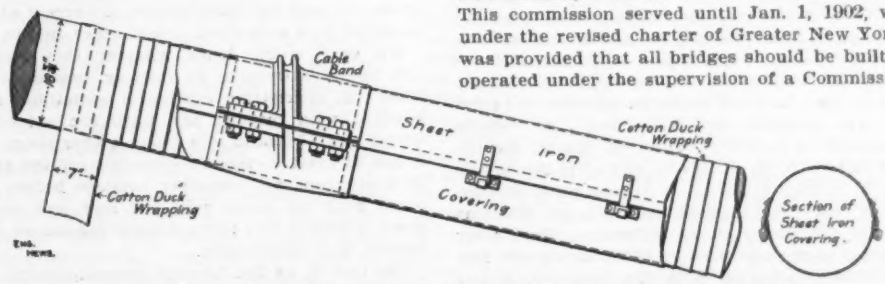


FIG. 9. SECTION OF SUSPENSION CABLE SHOWING COVERING.

Quantities.

The quantities of the different principal materials used in the construction of the bridge were approximately as follows:

Towers (each 3,048 tons), tons	6,096
End spans, tons	6,140
Brooklyn approach, tons	6,085
New York approach, tons	10,350
Suspended span, tons	7,772
Cables and suspenders, tons	5,000
In anchorages, tons	3,100
Concrete, cu. yds	60,000
Stone masonry, cu. yds	130,000
Excavation, cu. yds	125,000
Timber, ft. B. M.	8,000,000

Progress of Work.

The following figures show the dates of beginning and completing the several parts of the bridge, where these have not already been given above: Manhattan anchorage began Oct. 15, 1897, and completed June 28, 1900. Brooklyn anchorage began Oct. 27, 1897, and completed Dec. 29, 1899. Manhattan tower foundations began Nov. 7, 1896, and completed in September, 1898. Construction of towers and end spans began about Feb. 21, 1899, immediately after the award of the contract, and completed about May 1, 1901. Construction of suspended span began immediately after the award of the contract, on May 8, 1901, and completed Dec. 7, 1903. The construction of the Brooklyn approach was begnn about Dec. 7, 1900, and was completed in November, 1903. Cable making was begun Nov. 29, 1901, and was completed in August, 1902. The total cost of the bridge, exclusive of the site, was about $11,000,000.

Administration.

The administration of the bridge during construction was vested in a Board of Commissioners until Jan. 1, 1902, and after that date in the Commissioner of Bridges of New York city. The first Board of Commissioners was appointed in June, 1895, and consisted of the following six members: For Brooklyn, Andrew D. Baird, Henry Batterman and James A. Sperry, and for New York, Salem H. Wales, F. B. Thurber and Richard Deeves. A second commission was appointed in January, 1898, and consisted of the following members: For Manhattan, Lewis Nixon, Smith E. Lane and Jas. W. Boyle, and for Brooklyn, Julian D. Fairchild, John W. Weber and James D. Bell. This commission served until Jan. 1, 1902, when under the revised charter of Greater New York, it was provided that all bridges should be built and operated under the supervision of a Commissioner of Bridges. The Commissioner of Bridges since that date has been Mr. Gustav Lindenthal, M. Am. Soc. C. E. The first Board of Commissioners appointed Mr. L. L. Buck, M. Am. Soc. C. E., as Chief Engineer, and Mr. O. F. Nichols, M. Am. Soc. C. E., as Assistant Chief Engineer, and these two gentlemen served in their respective capacities until Jan. 1, 1902. On the appointment of Mr. Lindenthal as Commissioner of the Department of Bridges, he appointed Mr. L. L. Buck as Chief Engineer of the Department, and Mr. O. F. Nichols as Engineer in Charge of the Williamsburg Bridge.

On May 1, 1902, Mr. Buck was appointed Consulting Engineer of the Williamsburg Bridge, Mr. Nichols retaining the position of Engineer in Charge until July 1, 1903, when Mr. H. D. Robinson was appointed Engineer in Charge.

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ADVERTISING RATES: 20 cents a line. "Want" and "For Sale" notices, special rates, see page XXIV-XXIX. New copy for standing advertisements should be received one week in advance of publication; new advertisements, Monday morning. The pages containing "Want," "For Sale" and "Proposal" advertisements are held open until Wednesday noon.

The latest news concerning the epidemic of typhoid fever now raging at Butler, Pa., indicates that the outbreak there will be the most serious one that has occurred since the true nature of the disease and the possibility of taking sanitary measures to prevent its spread became generally known.

In view of the great scientific interest and importance of this epidemic, and the lack of reliable information as to its origin, Engineering News has engaged Mr. Geo. A. Soper, Ph. D., Assoc. M. Am. Soc. C. E., to make an exhaustive report upon the epidemic and its causes. Dr. Soper's experience as sanitary expert in charge for the State at Ithaca, N. Y., during and after this year's typhoid epidemic there, his recent work in connection with the typhoid epidemic at Williams College, and his work at Galveston, Tex., after the great storm and flood of 1900, have given him a wide reputation in both the engineering and the medical profession.

We hope to present an exhaustive report from Dr. Soper on the situation at Butler in our next week's issue. At present we are able to give our readers the following interesting preliminary statement sent to us by Dr. Soper, after a day's investigation at Butler:

Sir: After enjoying practical immunity from typhoid fever for many years, the town of Butler, Pa., is now passing through what is probably the most severe epidemic of typhoid of which we have any recent record. Up to noon of Dec. 14, the total number of cases known to the authorities had been 1,247, and there had been 51 deaths. New cases are occurring daily, and it is clear that the epidemic is by no means over. It is probable that the death list will be much increased, since about 50% of the cases have not yet reached a critical stage.

The cause of the epidemic is universally regarded as the public water supply, which apparently became infected near the end of October. The water for the town is obtained from surface sources and, under ordinary circumstances, is treated by mechanical filtration. Owing to changes in the water-works plant, due partly to the necessity of increasing its capacity, unfiltered water from Conoquenessing Creek was supplied to the town from Oct. 20 to Nov. 2. On Nov. 5 the epidemic started and in three weeks there were over 1,000 cases.

Inspections of the drainage areas made by the Pennsylvania State Board of Health have shown the existence of numerous sources of pollution. Cases of typhoid have existed on the banks of the Conoquenessing since July last.

There are hundreds of people in want at Butler. The fever has, in some instances, prostrated whole families. The work of supplying the needs of the sick is being carried on under the direction of a committee of citizens chosen in mass meeting. Mr. J. N. Moore is chairman of the executive committee. Money is needed for the relief work and a call for $75,000 may soon be made to the public.

The State Board of Health has undertaken to carry on such operations in the line of disinfection and of protection of the present water supply of Butler as may, in its judgment, be called for. Dr. Wilmer R. Batt, State Quarantine Officer, represents the State Board.

George A. Soper.

Butler, 5 p. m., Dec. 14, 1903.

Already the Butler epidemic has served as a warning to many communities to arouse themselves and guard their public water supplies and their citizens from a similar peril. It is probable that the lessons of the Butler epidemic, which will become apparent with the publication of Dr. Soper's full report, will be to the effect that neglect of ordinary safeguards in the design and operation of water-works, and lax sanitary administration, and in some cases complete lack of efficient health board work, are to-day subjecting hundreds of communities to the danger of as great a calamity as that now visiting Butler.

The paper printed in this issue on the comparative merits of direct current and alternating current motors for long distance electric railway work will be examined with interest by engineers engaged in this field, because of the definite and authoritative figures which it gives as to the detail cost of equipment and operation by the two systems. The paper, we judge, may be taken as a fair statement of the claims for the alternating current system; and we are inclined to the belief that, on the face of the showing made, the general opinion will be that the advantages of the alternating current system are not sufficient to justify a change from the direct current system, with which engineers are already familiar.

By Mr. Lincoln's own figures, the adoption of the alternating current system will save in the first cost of electrical equipment for a 60-mile road only 16% of the first cost and only about 7% of the operating expenses; and it involves the collection of current at 3,000 volts potential from a bare overhead wire suspended just above the roof of the car and the transmission of current at that potential to a step-down transformer on the cars.

We very much doubt whether this proposal will sound attractive to railway managers. A 3,000-volt alternating current is something to be handled with respect, and until the art of car wiring has advanced to a much higher stage than it has at present, those responsible for the safety of passengers will certainly hesitate before they place such an agent over the roof and lead it down a trolley pole to machinery carried on a car loaded with passengers.

The fact is, as Mr. Lincoln himself admits, that the main reason why the alternating system is cheaper in first cost than the direct current system is because the current is distributed at very high tension. Reduce the voltage in the alternating current system to that which experience with direct current has shown to be safe, and the advantage of the alternating system disappears. We must say that this appears very much like economizing at the expense of safety.

Another point that will be noticed in the alternating current proposition is that the electrical equipment on a car weighs 6.3 tons more than the direct current equipment. Mr. Lincoln makes allowance for the additional power required to haul this greater weight, but he does not make any allowance for the increased wear on track and rail joints of the heavier car.

The complicated machinery on the car necessary to enable it to make use of the direct current when running in city streets and of alternating current when in the open country furnishes still another reason why a change from the well-tried direct current system does not seem worth while.

In commenting last week upon the plan for erecting the eye-bar cables for the Manhattan Bridge at New York city, it was stated that it was proposed to expand the bars by heat to facilitate the task of threading them onto the pins. While this plan has been considered by some of the engineers of the Bridge Department, we are informed by Mr. Gustav Lindenthal, Commissioner of Bridges, that he has never seriously contemplated it and regards it as both unnecessary and impracticable. He anticipates no more than the usual difficulties of eye-bar erection in the construction of these cables. As stated, a chain of alternately one-bar and two-bar links will be connected up, and then the other bars will be threaded onto the pins, which will be fitted with pilot nuts to facilitate the operation.

The admirable paper on the cost of concrete tunnel lining, printed in this issue, is an example of a class of papers which engineers ought to contribute more freely to their professional journals.

We doubt whether there is any portion of an engineer's work which is so highly valued by the public, and which does so much to increase public confidence in the engineering profession as the making of careful and reliable estimates of cost. There is reason in this, for there is hardly a task which the engineer can undertake which will more thoroughly test his breadth of knowledge, his familiarity with the world of commerce and finance and his ability to render a sound and unbiased judgment than the preparation of detailed estimates for large and important works.

For the preparation of estimates, however, that shall be accurate and reliable, the engineer needs, first of all, recent records of the cost of similar work and the more such records he has available, the greater the confidence with which he can prepare his estimates.

We need say no more, surely, to prove the great value of such records, or to emphasize the service to his profession that is rendered by every engineer who takes the pains to prepare such records for publication. It is true that difficulties are almost always met whenever any proposal is made to publish an accurate statement of costs of work done; but this makes it all the more creditable when an engineer is able to defy precedent and cut red tape in order to publish facts useful to his professional brethren.

Now that engineers and contractors are looking forward to actual construction work on the Panama canal at an early date, it becomes of interest to discuss what allowance must be made for the unhealthful conditions of the Isthmus. In an interview published in the Cleveland "Leader" of Dec. 10, Mr. L. E. Cooley, of Chicago, expresses the following opinions:

The Panama Isthmus is not only unfit for colonization, but life there is a constant battle against unhealthy conditions. A large percentage of the workmen, mostly blacks from Jamaica and other West India Islands, will be a drunken, disorderly lot. They will attract a parasitic camp following of the riff-raff and criminal outcasts from the large cities everywhere.

An elaborate and costly hospital and sanitary system must be established, as well as efficient police. On the Chagres River it might be found expedient to locate the camp dwellings high up in the hills, a thousand feet or more above the sea level, and well removed from the miasmatic and fever-laden vapors that overhang the swamps and lowlands. The men could be transported to and from their work daily on electric tramways similar to our suburban trolley lines. The cost of building and operating the tramways would be offset by the lowering of the death rate and the lessening of the outlay for hospital service.

The unhygenic conditions and the intolerable heat of the Isthmian climate will, in the final reckoning, add materially to the bill of cost. Mechanics and skilled laborers from the North will demand and will obtain more than double the wages they would earn in this country. It was the experience of the dredging contractor for the Panama Canal that he was obliged to pay exorbitant prices for skilled labor. Probably the estimates of the Isthmian Canal Commission should be enlarged by a considerable percentage—how much no man can guess—because of the disheartening difficulties which are created by adverse climatic conditions.

To appreciate the fact that Mr. Cooley does not at all overstate the risks involved in assembling thousands of laborers in construction

camps on the Isthmus, one has but to recall the very recent records of fever epidemics in the military camps established in the United States at the opening of the Spanish-American war. These camps were chosen with particular regard to sanitary surroundings. They were located in the temperate zone. Their population was made up of a high grade of men, selected with greatest regard to physical perfection, and all of them under military discipline.. Yet with all these and other advantageous conditions that might be enumerated, disease ran riot in camp after camp.

Contrast with these conditions the conditions that will obtain in the fever-smitten swamps of Panama and the risk involved in bringing together there the great hordes of laborers that will be required in the work of construction. It must be evident that the best that skill and money can do to improve the sanitary conditions and lessen the risk of epidemics will be well expended, not alone from the humanitarian point of view but because of an ultimate reduction in the total cost of construction.

The paper on a high-duty distilling apparatus printed in this issue records a particularly interesting investigation, which may yet prove to be of large commercial importance. In most thermodynamic operations with which the engineer has to do, heat is expended to do work and there are pretty rigid limitations as to the possible economy that may be obtained. In the distillation of water, however, it is theoretically possible to carry on the process without the expenditure of any heat whatever, if we had an ideal means of heat transmission.

Thus, suppose we have a heat transmitting apparatus into which a stream of water flows, and is heated to the boiling point and evaporated into steam by the application of an external source of heat. Now let us pass this current of steam along in contact with the entering water. If we could extract from this steam all its heat and impart it to the entering water, that in its turn would be heated to the boiling point, and the departing current would issue from the outlet cooled to its original temperature. Thus, under such ideal conditions of heat transmission, and with an ideal non-conductor to prevent external loss, the process, once started, could go on forever without the application of any more heat.

Of course, as a practical matter, an infinite efficiency is an impossibility. What can be done and what is already done is to follow out to some extent the regenerative principle, so that with the best double and triple-effect distillers an efficiency as high as 30 lbs. of water per pound of coal is sometimes reached.

What Professor Goss has done is to experiment with multiple-effect evaporators having a larger number of steps than the triple-effect, and his paper is well worth study by any who wish to investigate the possibilities of economical distillation. It will be apparent that the possibilities of commercial success in any such step distilling system are largely dependent on the production of cheap heating surface. With this, however, comes the requirement that the heating surface must be so arranged that the solids produced by the distillation may be readily and cheaply removed, and this is perhaps the most difficult part of the problem to solve.

THE ENGINEERING OUTLOOK FOR 1904.

The year 1904 promises to be one of unusual importance in the annals of engineering progress on the North American Continent, taking that term in its literal geographical sense. In all human probability we will see inaugurated in the coming year several great engineering works, great not only in the magnitude of the operations involved, but in their prospective influence upon commerce and industry, both national and international. Each one will call for all the resources and inventive talent of both civil and mechanical engineers, and all the energy and accumulated experience of the men who are accustomed to handle men and machinery in the execution of public works.

The first of these great tasks to be undertaken is the construction of the Isthmian canal, which now seems to be an assured fact, after years spent in investigation and diplomatic negotiations, and after numerous attempts and spectacular failures by private corporations. The dimensions of this problem are vast, as measured by similar enterprises in other parts of the world; and the opportunity will now be given to American engineers and American contractors and builders of machinery to utilize all that knowledge, skill and experience in conducting public works that has already done so much to make our own country great. The economical solution of the problem calls for mechanical appliances, to a degree almost unprecedented, and for this machinery we confidently look to our own engineers and to our own shops.

The climatic conditions will demand the utmost endeavor in the way of organization and the care and handling of labor; and last, but not least, the engineering features involved are so unusual and of such huge dimensions that the latest sum of engineering genius and experience can alone bring about successful results. The technical record of the conduct of this work should add a new, novel and most important chapter to the history of the world's engineering progress.

Another great engineering enterprise, already started, but to be energetically pushed in 1904, is the plan of the Pennsylvania Railroad Company to connect its system with the cities of New York and Brooklyn by tunneling under the Hudson and East Rivers. Here again is a problem that in its solution includes new and practically untried engineering methods. The mere fact that so great an organization proposes to risk its tens of millions in venturing upon a path untrodden before, is a measure of its confidence in the wisdom and skill of the modern engineer, and in his ability to succeed under conditions that would have halted the greatest among his professional predecessors.

In the state of New York, the popular vote technically approves of the expenditure of a hundred or more millions upon the 1,000-ton barge canal, connecting the Great Lakes with the Atlantic seaboard. The execution of this work again calls for the latest practice in engineering and the latest appliances for executing work.

In many of the inland states the companies controlling the great railway systems have an enormous volume of work, either in progress or contemplated, which has for its object the creation of new works to take the place of those planned and executed by a past generation of engineers who were compelled by limited means to adopt the cheapest method of accomplishing the end in view—that of furnishing some means of railway communication between distant points.

The enormous traffic developed by the growth of our domestic commerce has brought into use heavier locomotives, larger cars and stronger bridges; and the resulting saving in operating expenditures now warrants an outlay for reduction in distances, gradients and curvature that would have been deemed wasteful extravagance by the preceding generation.

Northward, in the Canadian possessions, the coming year will doubtless see a notable beginning made in what will become another great transcontinental railway. This Grand Trunk Pacific Railway will be nearly 4,000 miles long, and will connect the Atlantic seaboard at Halifax with the shores of the Pacific Ocean, at Port Simpson. It will be the most northerly railway line of importance on the continent, practically following for much of its length the great divide separating the waters of the St. Lawrence basin from those of Hudson Bay. Its purpose is to open up to population, trade and commerce vast areas of wheat land, timber land and mines that are now valueless by reason of the lack of transportation facilities. Aside from its purely economic features, this proposed work is interesting to our readers because its projectors announce that they will make the construction of this road a model for twentieth century railway practice. In the organization and work of its survey parties, in the details of execution, in the housing and care of its labor, in the application of machinery wherever machines will be productive of economical and rapid work, we are to look for the latest practice, the newest and best inventions and the utmost of human energy and skill.

With these enterprises once fully started—as they will be in 1904—there should be abundant demand for the services of the engineer, for the designer and maker of all types of engineering machinery and materials, for the men who handle machines and labor, and for labor itself.

A DISCUSSION OF TWO CONTRACT CLAUSES:—(1) "OMISSION IN PLANS;" (2) "POWERS OF ENGINEER."

The Engineering Association of the South has recently published some very interesting discussions of specification clauses, and, as we believe that just such discussions will eventually lead to the writing of better specifications, we give space to the discussion of two general clauses that are found in almost all specifications. They are:

(1) OMISSIONS IN PLANS.—Corrections of errors or omissions in drawings or specifications may be made by the engineer when such correction is necessary for the proper fulfillment of the intention of such drawings or specifications, the effect of such correction to date from the time that the engineer gives due notice thereof to said contractor.

(2) POWERS OF THE ENGINEER.—To prevent all suits and litigation, it is further agreed by and between the parties to this contract that the engineer shall in all cases determine the amounts of work done which are to be paid for under this contract; that he shall be the sole judge of the manner of construction, of the quality of materials, and of the interpretation of the specifications; that he shall decide all questions which may arise relative to the carrying out of this contract; and that his estimates, figures, measurements, directions and decisions shall be final and conclusive, neither party to this contract having recourse to the opinion of other experts.

Herman Alber: In this discussion one thing must have certainly impressed any outsider who might have chanced to be present—i. e., the general desire on the part of all engineers who took part in the discussion to lay stress on the fact that contractors be not dealt with in an arbitrary manner, and that the contract and the specifications be construed in a liberal and reasonable spirit. I believe that the desire to act in such a spirit is shared by all engineers, with few exceptions. I have asked myself: "Why is it that all specifications issued by large corporations, who often have contracts to give out, contain such clauses as those under discussion?" This refers not only to this country, but, for instance, to specifications under which railroads are built in Germany. The presumption that contractors often desire to escape even a fair application of specifications is certainly greater than the one that engineers attempt to apply them too strictly; for on the part of the contractor the desire to make money comes in, while this motive is certainly absent on the part of the engineer. At the termination of a contract, during a discussion with the contractor's timekeeper, I received from him the reply to my question as to whether he had already secured another position, that he could have one at any time from a large contractor in the East, but that he did not like to work for him, as he paid only small wages, expecting the timekeeper to make up the deficiency in wages by getting a percentage from the manipulation of the time book. Aghast at such a statement, several men who had been engaged by the contractor answered my astonishment with a broad smile and the information that the contractor mentioned was not the only one engaged in such tricks. Now, if there are a number of contractors engaged in such deals with their own men, what may engineers not expect from them in regard to their intentions toward corporations, especially when it is taken into consideration that there is a general unfair spirit displayed toward them all over the country, and by other classes (witness the awards given by the average jury in damage suits against companies)? The evolution of specifications to their present shape has obviously been caused by very unpleasant experiences on the part of those who have contracts to let; and I believe that such clauses as those under discussion have found their entrance due to the desire of having a weapon which, in dealing with fair-minded contractors, is left in its scabbard, but which can be drawn if others are encountered. To word such clauses in a manner which will stand the test of law is a question of a different color.

H. Schoel: In regard to the power of the engineer to correct errors and omissions in plans, I think that the clause should read: "When such correction is necessary, in the opinion of the engineer, for the proper fulfillment of the intention of such drawings," etc. A provision should also be made that if such correction entails a greater or lesser amount of work on the part of the contractor, then the engineer shall determine the value of the work added or omitted; and, in case of disagreement, the value of such work shall be determined by three disinterested parties. I think that the first part of the clause concerning "powers of the engineer," which makes the engineer the sole and final judge of the quality of the work and of the materials, as well as of the interpretation of the specifications, is perfectly fair and should stand. The latter part of the clause, however, making the estimates of the engineer final and conclusive and forbidding either party to the contract to have recourse to other experts, is, in my opinion, not quite just and fair;

and an insistence upon it by the engineer making the estimates will surely injure his reputation. "Errare est humanum" is true of engineers as well as of other mortals; and infallibility should never be claimed by, nor ever be conceded to, any human being, the Pope of Rome not excluded. If I were the engineer in charge of any piece of work and any party to the contract should object to my estimates, I would not only be willing to, but would insist upon, a revision of my estimates by another competent engineer. To refuse such verification would only arouse the suspicion of the party objecting that he was to be victimized. Not very long ago a contractor who had done the grading at one of the great industrial plants which the Association visited this summer came to me complaining that in his opinion he did not get a fair estimate of the work done by him, and asked me to revise the estimates of the engineer in charge. I told him I would go over the estimates with the other engineer if the latter would submit the original topography. This, however, was refused by the engineer in charge; and I cannot help believing now that the contractor really was dealt with unfairly.

Woolsey Finnell: In my opinion, the clause (2) under discussion should not appear in any contract. I do not say this because I think the engineer takes advantage of it to the detriment of the contractor; I say it because none of us are infallible. Therefore, if the parties to a contract cannot agree to willingly submit to the decision of the engineer in charge, I hold that either party has a right to employ other engineers to pass on the work, to resort to arbitration, or even in very extreme cases to resort to a "court of equity." Our courts hold that a man cannot sign his life, liberty, or common rights away. This being the case, such a clause is absolutely worthless, and only tends to oppress the weak and ignorant. It has been claimed that it is a good thing to have this clause in contracts in order that unruly sub-contractors may be bluffed into line and not give any trouble to the head contractor or engineer in charge. Gentlemen, I protest against any such use of this clause or any other clause. My experience has been that where sub-contractors were treated fairly by all parties they gave very little trouble. The way to get good work out of a sub-contractor is to let him know at the beginning of the work that the engineer directly in charge of his work will tell him the yardage in any cut, fill, ditch or any other work he may have; that he will get a statement of his estimate from the engineer, and not have to wait for a "copy" from the chief engineer's office, that copy being sent through the head contractor. My observation has been that engineers are apt to give the benefit of all doubts to the contractor. A great deal of trouble that is supposed to come up over this clause really comes from the contractor's taking work too cheap, but that is no reason why the clause should be in a contract. It is misleading to the ignorant, acts as a bluff to the timid, is absolutely worthless and ineffective when put to the test, and, therefore, should not appear in any contract.

Mr. Finnell has expressed in vigorous English what we believe is now the opinion of the majority of engineers, and that is that the insertion of a clause to be used to bluff ignorant or timid contractors is never justifiable. Moreover, we may add, such a clause defeats its very purpose, because it does not prevent lawsuits, but tends rather to foment trouble between the engineer and the contractor, often leading to litigation.

There is another feature about such a clause that has seldom been touched upon; we refer to the interpretation put upon it by uneducated inspectors or by inexperienced engineers. The direct supervision of work is often in the hands of such men; and with such a clause for his justification it is a very common thing to see an inspector acting in the most arbitrary and lordly manner. Acting thus he is quite certain to get into serious trouble with the contractor or his foreman, and working at loggerheads seldom leads either to efficient or to good work. If the work is well done but inefficiently done due to little hindrances created by the inspector, then there may be no loss under the first contract; but any subsequent contract will be bid in at a higher price, so that eventually the company doing the work must foot the bill. The insertion of unreasonable and unfair clauses leads inevitably to higher average prices for contract work, or to a less honorable class of bidders.

LETTERS TO THE EDITOR.

The Money Value of Technical Training.

Sir: I am very much pleased with your clear and interesting editorial in your last issue on my paper on "The Money Value of Technical Training." The position you take is, in my judgment, perfectly justified, and your words of warning I hope will be heeded, as they deserve. I feel very grateful to you for your fair and kindly treatment of my address, and thank you most sincerely.

Yours very truly, James M. Dodge.

Nicetown, Philadelphia, Dec. 11, 1903.

Napoleon and the Metric System.

Sir: I read the following in the "Journal" of General Baron Gourgaud, which has lately been translated from the French and published in this country. On page 86 it is stated that Napoleon said:

I never have approved the system of weights and measures adopted by the directors and invented by Laplace. It is all based on the meter and conveys no ideas to my mind. I can understand the twelfth part of an inch, but not the thousandth part of a meter (millimeter). The system created much dissatisfaction with the directory. Laplace himself assured me if, before its adoption, all the objections I made to it had been pointed out to him, he would have recognised the defects and have given it up.

Yours truly, S. Munch Kielland.

Buffalo, N. Y., Dec. 7, 1903.

Work Train Service.

Sir: I have noted your editorial remarks on "Work Trains" in Engineering News of Dec. 3, and my impression is that the degree to which the work train is regarded as a nuisance is dependent largely on the form of the management. If the Transportation Department and the Road Department are entirely separate, the transportation officers will consider a work train a nuisance, as they have no interest in its work and it interferes with theirs. But if the administration of both departments is vested in a superintendent who is equally responsible for results in each department, it will be found that adjustments will be made helpful to both lines of work, and that the feeling that the work train is a nuisance will be very much modified. All of this is an argument in favor of division organization as against departmental organization.

Very truly yours,

A. W. Sullivan,

Asst. Second Vice-President, Illinois Central R. R.

Chicago, Dec. 7, 1903.

Mr. Spring's Formula for Safe Limit of Wheel Loads Upon Rails.

Sir: In commenting on Mr. Spring's paper on "Permissible Wheel Loads" in your issue of Nov. 19, you take exception to his formula on the ground that, as you think, the maximum permissible load is not proportional to the diameter of the wheel.

I believe that Mr. Spring's formula is theoretically correct in form, and may be verified as follows:

Let W = permissible wheel load
P = maximum pressure allowable on area of contact
D = diameter of wheel
w = width of wheel
E = modulus of elasticity.

We may assume that $W = E^x P^y w D^z$ (1)

By substituting for each of the quantities in the above equation their dimensions in the fundamental units, we obtain

$$L M T^{-2} = (L^{-1} M T^{-2})^{x+y} w D^z$$

In this equation $(x + y)$ and z can have no other values than unity: Therefore equation (1) becomes

$$W = E^x p^{1-x} w D,$$

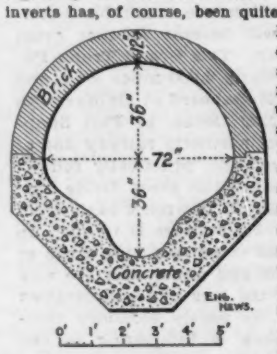
which agrees with Mr. Spring's rule.

Yours truly. W. H. Adamson.

Montavilla, Ore., Nov. 31, 1903.

A Large Concrete and Brick Sewer at Corning, N. Y.

Sir: I read an article in Engineering News of Nov. 26 regarding concrete-brick sewers. The use of concrete for inverts has, of course, been quite common for some time. Its use has not been so common, however, for sewers too large to be made oval and which are used both for house sewage and storm water. Its use is particularly advisable in this case, since the cross-section is then merely a question of templet and can be designed so that there will be a large hydraulic radius in time of minimum flow and nothing like a shelf to catch objectionable material when the flow is diminishing. I send herewith a sketch showing the cross-section of a concrete-brick sewer recently designed for a system of sewers in Corning, N. Y.



Cross-Section of Large Concrete and Brick Sewer at Corning, N. Y.

Yours truly,

Palmer C. Ricketts.

Troy, N. Y., Nov. 28, 1903.

General Specifications for Railway Bridges.

Sir: Referring to the communication in your issue of Dec. 3 by Mr. J. L. Campbell regarding general specifications for railroad bridges, I beg to call attention to the work on this subject being done by the American Railway Engineering and Maintenance of Way Association. At its annual convention last March this association adopted a specification covering material and workmanship which has since been printed in pamphlet form and is now on sale by the secretary.

Through its committee the association has been at work on this subject for three years and its publications contain much material, leading towards a uniform specification, other than that connected with the quality of material and workmanship. All phases of the subject are under study, and it is hoped that in due time something may be agreed upon that will tend to reduce the vagaries that Mr. Campbell complains of.

The matter so far published by the association is open to discussion and criticism by all who may be interested, and much benefit would result if bridge designers, bridge manufacturers and bridge buyers would communicate freely with the secretary of the association.

Yours truly, J. P. Snow,
Bridge Engineer, Boston & Maine R. R.

Boston, Mass., Dec. 7, 1903.

(The Secretary of the American Railway Engineering and Maintenance of Way Association is Mr. L. C. Fritch, Washington, Ind.—Ed.)

Strength Tests of Mixtures of Hydrated Lime and Portland Cement.

Sir: Some time ago we made public a table showing the relative strengths of different mixtures of "Limoid" and Portland cement, giving therein tests up to three months in length. We have just received the one-year tests of the same samples from Booth, Garrett & Blair. These one-year tests in comparison with the shorter time tests are extremely gratifying, showing an excellent increase in strength by age in every case; in fact, a percentage increase between three months and one year, which is very rarely, if ever, shown in cement tests. We presume that the large percentage increase in one year is largly due to the more gradual setting and strengthening properties of lime, which, as is well known, requires some time to work into its final carbonic and silicate forms. The publication of the averages shown in these tests may be of interest to your readers, particularly those who are now becoming more interested in the manufacture and use of hydrate lime.

There is one interesting point to be brought out in connection with these tests, viz.: That ordinary good mixing of dry sand, hydrate of lime and cement will produce just as good, if not better results than when grinding the hydrate and Portland cement together in a ball mill for one hour, as shown by the special test on the last column. It was thought by many people that the thorough mixing and grinding together of the hydrated lime and Portland cement would produce a considerably stronger effect, but this appears to be a wrong theory, and we are much gratified to find that it is so, as it makes the question a comparatively simple one to work out for practical use.

Very truly yours,
Charles Warner Co.,
Wm. H Malley, Asst. Secretary.

(The average results mentioned by our correspondent are given in the accompanying table. In this connection it may be noted for the benefit of those interested that an article describing the manufacture of hydrated lime was published in Engineering News of Aug. 27, 1903, and was supplemented in the succeeding issue of Oct. 8, 1903, by a valuable letter from Mr. Charles Warner.—Ed.)

Results of Tests on Mixtures of "Nazareth" Cement and "Limoid."

	1½ Llo. 1 part Naz.	1¼ Llo. 1 part Naz.	¾ Llo. 1 part Naz.	½ Llo. 1 part Naz.	1 part Llo. 1 part Naz. (Special)*
	lbs.	lbs.	lbs.	lbs.	lbs.
7 days	81	101	119	129	137
28 days....	134	144	173	179	169
3 months..	148	154	217	181	174
1 year....	245	228	288	281	224

*Limoid and Nazareth were ground for one hour in a ball mill.

Note.—Tests on Nazareth cement alone, same as used in above mixtures tests, gave the following results:

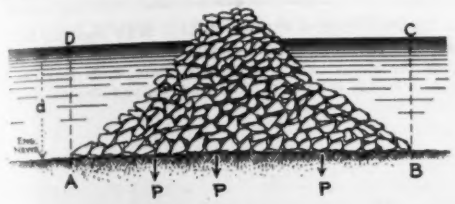
7 days, neat.....644 608 640 672 638—Average 632
7 days, 1 part cement, 2 sand .....340 345 360 354 336—Average 347

A Problem in Hydrostatics.

Sir: I would like to have your opinion on the following: Take a large deposit of stone resting on the bottom of a large body of water and extending above the water surface. What is the pressure on the bottom? Should we

take the weight of the superincumbent mass as it weighs in the air, or the weight of the mass less the weight of water = 62½? If the stone weighs 162½ lbs. per cu. ft. in one case the pressure would be d × 162½; in the other, d × 100. Which is correct? Pressure.

(Strictly speaking the answer to our correspondent's question, "Which is correct?" is, "Neither;



for his sketch shows stone above the water surface, while his formula contains only the factor d for stone below the surface.

The problem reminds us of an old one in a high school physics which ran something like this:

A block of wood floating in a bucket of water has no downward tendency, since its weight is balanced by the weight of the water displaced. Now, place the bucket of water with the floating block on a platform scales and weigh it. Remove the block of wood. Will the scales show any difference due to the removal of the wood which had no downward tendency?

The wording that puzzles the beginner in physics is "downward tendency." He is led to err by regarding the absence of "downward tendency" as being equivalent to an absence of weight. But if he considers the conditions for a moment it becomes clear to him that nothing can really deprive a body of weight, and that the load on the platform scales is immediately reduced by the removal of the block of wood by an amount exactly equal to the weight of the block of wood. So in the problem of our correspondent, the bottom of the lake from the point A to B has to support the weight of the stone (as weighed in air), plus the weight of the water left in the rectangle A B C D after the stone has crowded out its bulk of water.

Again, we repeat that neither of the formulas given by our correspondent will give the total weight on the bottom of the lake.—Ed.)

The Harlem River Tunnel for the New York Rapid Transit Railway.

Sir: For the construction of the east half of the river portion of the Harlem River Tunnel in this city for the Rapid Transit Railroad, I am prepared to say that the method I have adopted therefor and am now carrying out will be a great improvement on the novel method under which I successfully constructed the west half of the river portion of said tunnel, as described in Engineering News of Oct. 8, 1903.

Briefly stated, the first method was to dredge a channel across the river bottom to within a few feet of the full depth of excavation required to build the tunnel. In this channel, foundation piles and a row of specially prepared heavy timber sheeting, along each side and across the ends, were driven and cut off to a true plane about 25 ft. below the surface of the water. This sheeting forms the sides and ends of a pneumatic working chamber.

For the roof of this chamber a platform of timber 40 ins. in thickness and extending the full width and length of the tunnel section, was built and sunk and rested on the cut off sheeting which formed the sides and ends as above described.

Simultaneously with pumping the water from under this roof compressed air was forced into the chamber under a pressure corresponding to the pressure of the water above the roof. Inside this chamber the west half of the tunnel was built and then the timber roof was removed.

The new method for the east half of the river, briefly stated, will be to prepare the sides of the pneumatic working chamber as above described, but the sheeting and piles will be cut off about 12 ft. lower down than was done in the former case, or exactly on the grade of the spring line of the arch of the tunnel.

The top half of the tunnel will be built at the surface on pontoons, then launched and floated over the tunnel site and sunk into its final and true position, the outward flanges of it resting on the cut off sheeting above described, then the top half of the tunnel will be used to form the roof of the pneumatic working chamber.

In this chamber the foundation and bottom half of the tunnel will be constructed, with the use of compressed air, thus dispensing with the timber roof as used in the first method and greatly decreasing the cost of the construction of the tunnel in many ways.

This method is bringing the construction of sub-aqueous tunnels to a fine point. It provides for preparing a foundation where the material under the bed of the river is not sufficient in itself. The sheeting which forms the sides of the working chamber is driven deep enough to penetrate and confine the earth material under the tunnel for several feet below sub-grade. The foundation piles driven in this confined material compacts it.

This method enables a tunnel ot be contstructed under a navigable river with the minimum depth of water over it that the U. S. Government requires for navigation.

For illustration, take the tunnel now being constructed across the East River from Battery Place, Manhattan, to Joralemon St., Brooklyn, by this method that tunnel may be raised 35 ft. higher than it is now located and still be below the U. S. Government dredging line; by thus raising it there will be 3,000 ft. of 3.1% grade eliminated.

With regard to safety and surety this method is to sub-aqueous tunnel work what pneumatic caisson work is to deep excavation work, viz.: absolutely safe and sure.

By this method the pneumatic working chamber is built in place immediately encompassing the work to be done, the pressure of the water on the outside of it is counterbalanced by the pressure of compressed air forced within it, consequently it is not subject to the heavy ordeal that a working chamber under a pneumatic caisson sunk from surface would have to undergo, therefore is much cheaper to construct.

This method enables the construction of a tunnel any desired shape or dimension. Tunnels where two or more railroad tracks are required may be built under the one roof and with partitions and intercommunicating openings where desired, whereas with the shield process they are limited to single-track tunnels and a circular form.

A double-track tunnel can be built under this method at much less cost than twice the cost of a single-track tunnel, a four-track tunnel at much less than twice the cost of a double-track tunnel.

This method enables the construction of tunnels with light grades in the sand across such rivers as the Ohio, Missouri and Mississippi, and provides against their being undermined. A modification of this method is provided for cases where the river bottom is rock, to bring the roof of the tunnel to the top of the rock if required.

By this method roadway tunnels with light grades for teams and foot passengers may be built across the Harlem river at a much less cost than bridges.

This method enables the construction of a tunnel with a light grade across the Detroit River at Detroit and avoids the difficulties that were encountered in the original attempt to build a tunnel at that place.

The use of compressed air in driving a tunnel horizontally with a shield is dangerous, a pressure of air sufficient to keep the water from running in at the bottom of the tunnel is liable to blow out at the face at the top of the shield, whereas with this method there is not any such danger.

The cost of a sub-aqueous tunnel built by this method as compared to a tunnel in our streets, the excavation for the tunnel in the river can be dredged out, consequently done much cheaper per cubic yard; less timber is required because the air pressure within the working chamber offsets the pressure from without. The advantage of building the top half of the tunnel in the open air at the river, as proposed above, over that of having to haul all the material to the street and place it, as must be done for a land tunnel, is obvious. The building of the lower half of the tunnel is somewhat in favor of the land section, but not to any great extent. Yours truly,

D. D. McBean.

Park Row Building, New York, N. Y., Dec. 10, 1903.

Notes and Queries.

Apropos of the discussion as to definiteness in specifying the ingredients of mortar and concrete, our attention has been called to the following clauses in Cooper's "General Specifications for Foundations and Substructures":

24. Cement mortar will be made by thoroughly incorporating the cement and sand in the following proportions, viz., one barrel of 300 pounds of Natural cement and 12 cubic feet of sand, or one barrel of 375 pounds of Portland cement and 16 cubic feet of sand, with sufficient water to obtain the proper consistency.

28. For foundations below the surface of the ground where the concrete will not be exposed to the action of running water or to weather, the concrete shall be made of the following proportions: For each barrel of Natural cement, 12 cubic feet of sand and 24 cubic feet of broken stone or coarse gravel.

29. For monolithic piers and abutments, for cylindrical and wooden box piers and for foundations where there is a liability to the action of running water or where the bottoh is soft or of unequal firmness, the concrete shall be made of the following proportions: One barrel of Portland cement, 10 cubic feet of sand and 20 cubic feet of broken stone or coarse gravel.

A STEAM SHOVEL OF NOVEL DESIGN.

A steam shovel in which all the operations are effected directly by steam cylinders is one of the latest developments in excavating machinery, and this new type of steam shovel, which is illustrated and described in the present article, dispenses with the usual equipment of hoisting engine, drums, chains (or cables), clutches, etc. Gearing is used only to propel the machine, a train of gearing connecting the engine with the forward axle. In the railway machine this gearing is replaced by a sprocket chain drive to one of the truck axles. In Fig. 1 is shown the railway shovel, with a bucket of 2½ cu. yds. capacity, at work stripping the site of a stone quarry, while Fig. 2 is a general elevation, showing the arrangement of the operating cylinders, etc. A similar machine is made, mounted on road wheels and having a 1¼-yd. bucket.

The underframe is 26 × 9½ ft., built up of steel I-beams and channels, and has a steel superstructure to carry the enclosing sides and roof, the corner posts being strong enough to serve as an attachment for stays supporting the head of the steel mast. This mast carries a triangular frame, at the apex of which is the main bearing of the boom. The mast is mounted on the turntable, and upon it slides the pivoted heel of the boom, the boom revolving upon a fulcrum bearing at about one-third of its length from the mast.

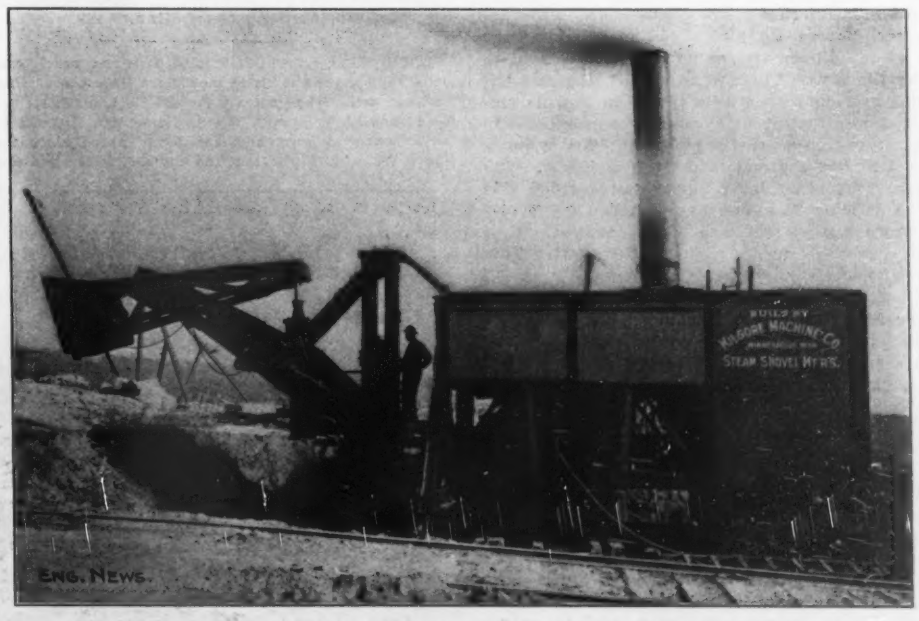


FIG. 1. STEAM SHOVEL OPERATED BY DIRECT-ACTING CYLINDERS.
Kilgore Machine Co., Minneapolis, Makers.

The dipper handle is pivoted to the boom, and both boom and handle are of steel construction, as shown. The horizontal reach of the machine, from center of mast to center and face of dipper is 25 ft. and 26 ft. 10 ins. respectively, instead of 20 ft. 3 ins. and 22 ft. 1 in., as shown in Fig. 2. The vertical reach from the rail to top of bucket when in its highest position is 25 ft.; and the vertical distance marked 12 ft. on the cut is now increased to 15 ft. Steam is supplied by a loco-

motive tubular boiler, 50 ins. diameter and 12 ft. long, and a double cylinder engine with cylinders 6¾ × 12 ins. furnishes the propelling power. The drawing shows a vertical engine, but the latest design provides for a horizontal engine alongside the swinging cylinder. This has a chain drive to a wheel under the frame, about midway between the trucks, and on the same shaft are chain wheels of smaller diameter with sprocket chains running to the inner axle of each truck. In operation, a fireman's platform extends beyond the rear of the machine. The weight of the machine with 1¼-yd. dipper bucket and mounted on railway trucks is about 30 tons. The weight of the 2½-yd. machine is about 65 tons.

The special features of the machine are in the method of handling and operating the dipper. These features include four direct-acting steam cylinders used in digging and swinging, and one small direct-acting steam cylinder for tripping the latch of the dipper. Within the mast is a vertical cylinder, from the crosshead of which are suspended cast steel links or connecting rods whose lower ends are attached to the heel of the boom. This cylinder raises and lowers the boom, and raises the dipper when making a cut. Pivoted to the main fulcrum of the boom is an oscillating cylinder, having its piston rod attached to the heel of the dipper arm or handle; this is used to swing the arm. The third cylinder (termed the forcing cylinder) lies within the boom, and its piston rod is attached to a cast steel crosshead to which the dipper arm is pivoted. This cylinder is used to give a direct thrust to the dipper. The fourth cylinder is placed horizontally at one side of the deck or floor, and has attached to its piston rod a heavy steel rack which engages with a steel spur gear on the foot of the mast. This serves to swing the mast and boom. The small tripping cylinder is attached to the lower arm of the frame, which carries the main bearing of the boom; its piston rod carries a rack, gearing with a spur wheel on the shaft of a small sheave on which is wound the chain running to the latch of the dipper bottom. Steam is carried to the several cylinders by lagged and jacketed pipes, the oscillating cylinder taking its steam through a hollow trunnion. Universal joints are used to allow for the necessary movements of the piping.

The cylinders are fitted with light balanced valves, operated by levers. The lever connections are such as to allow of the cylinders being operated singly or together, and two hand levers control the four main cylinders. The engineman stands on a platform which swings with the mast, and he holds one of these levers in each hand, while at his feet is a treadle or foot lever for operating the small tripping cylinder. He thus has a clear view and complete control of the operations of the machine. Only two men are required to operate the machine the engineman and the fireman, but there are of course the usual pitmen.

It is claimed that by the use of steam there is a great reduction in steam consumption, and also in the jar and vibration when at work. The cylinders are cushioned at each end of the stroke and can be worked at full stroke at high speed, without damage or shock. The steam is used expansively to a great extent, and the point of cut-off is under the control of the engineman. If the first truck should get off the track, the dipper can be lowered vertically till it rests upon the ground, and then by using the lifting and swinging cylinders the front of the machine can be raised and swung onto the track again. By the forcing cylinder, the dipper can be drawn back when full, instead of being run to the top of the cut. This movement is also used when spotting the dump cars alongside the machine. By using both oscillating and forcing cylinders, a straight horizontal thrust of the dipper along the ground is obtained, and it is said also that the dipper can be shaken violently to throw off large boulders or to clear it from sticky clay.

This steam shovel is the invention of Mr. Frederick O. Kilgore, and it is manufactured by the Kilgore Machine Co., of Minneapolis, Minn. Two or three of these machines have already been built and put in service, one of them being used for stripping at the quarries of the Kettle River Quarries Co., at Sandstone, Minn.

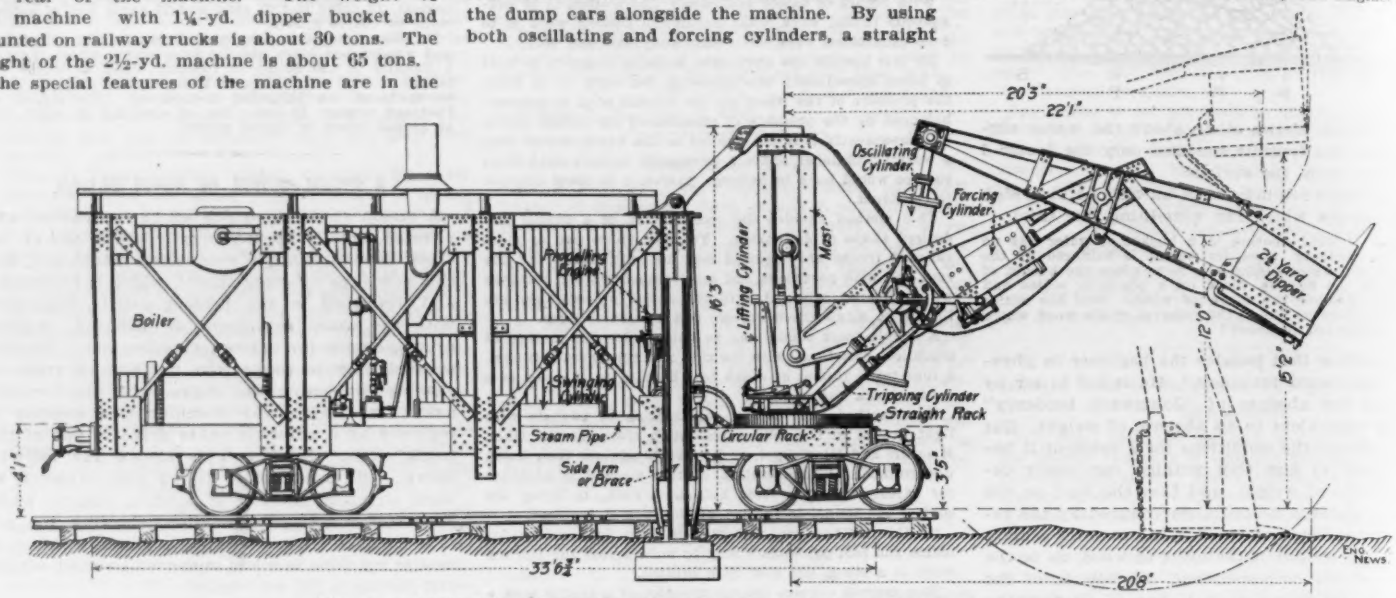


FIG. 2. ELEVATION OF STEAM SHOVEL WITH DIRECT-ACTING CYLINDERS.

LOCK NO. 9, KENTUCKY RIVER, is now nearly completed, and the first lockage took place Dec. 3, everything working well. The contract for this lock and dam was made June 12, 1901, with The Sheridan-Kirk Contract Co. Work began at once, and has been pushed since that time. While it is true that the contract is not yet completed, nor is the lock open to navigation, vessels can use the lock, when absolutely necessary for urgent reasons. Both lock and dam are of solid concrete, and the gates are of steel. The construction marks a decided advance and may be said to be as nearly permanent as possible. Navigation is carried from Valley View to Ford, 17 miles. At this point, the Mason & Hoge Co. are building Lock and Dam No. 10, a similar construction, and have placed some 19,000 cu. yds. of concrete during the past season, almost completing the lock; and it is expected that the whole will be finished next season, carrying navigation to College Hill, where Talbott & Co. have a contract for building Lock and Dam No. 11, of similar construction.

A CONTRACTOR'S STEEL WAGON WAY was laid for temporary use in hauling materials to the Greentree Tunnel on the Pittsburg, Carnegie & Western R. R., according to a recent article in "The Railway and Engineering Review" of Dec. 5. Loads of 6,500 lbs., or about 8,500 lbs. including the weight of the wagon, are hauled over ordinary roads as far as the foot of the hill leading to the eastern end of the tunnel. The hill is 800 ft. long, with some 15% grades, the ground being rocky and rough. Steel channels were laid so as to form a wagon way up the hill. Four loaded wagons are coupled together, without unhitching the teams, and a cable from a hoisting engine, located at the top of the hill, is hooked on to the leading wagon. The four teams are thus assisted up an ascent otherwise insurmountable with heavy loads. Kenefick & Co., of Kansas City, Mo., are the contractors for the tunnel.

COFFERDAM FOR THE 39TH STREET PUMPING STATION AT CHICAGO.

In the article on the intercepting sewer system of Chicago, in our issue of May 28 last, a plan was given of the pumping station to be erected on the lake front at the head of 39th St., delivering sewage and lake water to the 39th St. conduit leading to the Chicago River. Work on the foun-

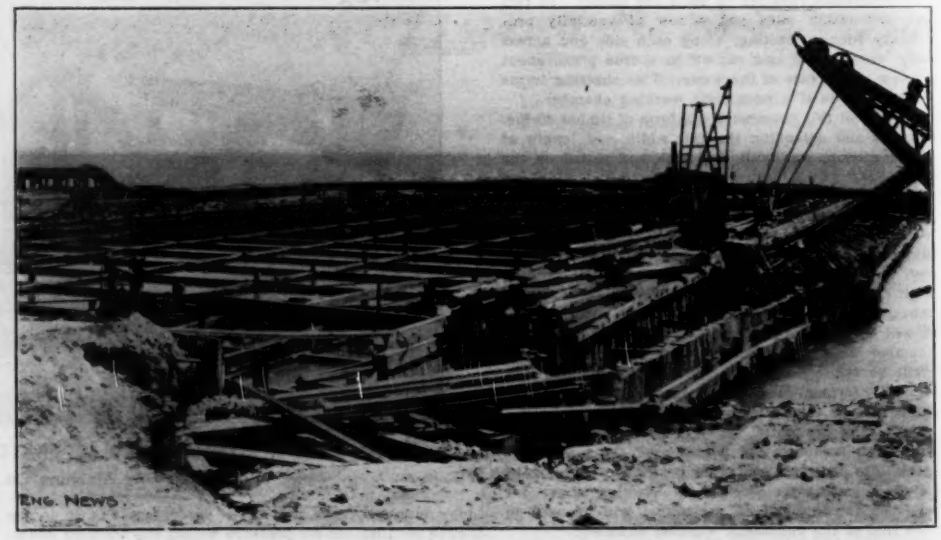


FIG. 1. COFFERDAM FOR THE 39TH ST. PUMPING STATION OF THE INTERCEPTING SEWER SYSTEM, CHICAGO (READY FOR PUMPING OUT).

dations of this station is now in progress, and the accompanying illustrations show the great cofferdam, which extends out about 500 ft. into the lake and is 190 ft. in width. It is believed that this is the largest cofferdam ever built in open water. The average depth of excavation within the cofferdam is about 24 ft., and is carried 7 ft. lower (to hardpan) for all footings. The concrete work will amount to about 25,000 cu. yds.

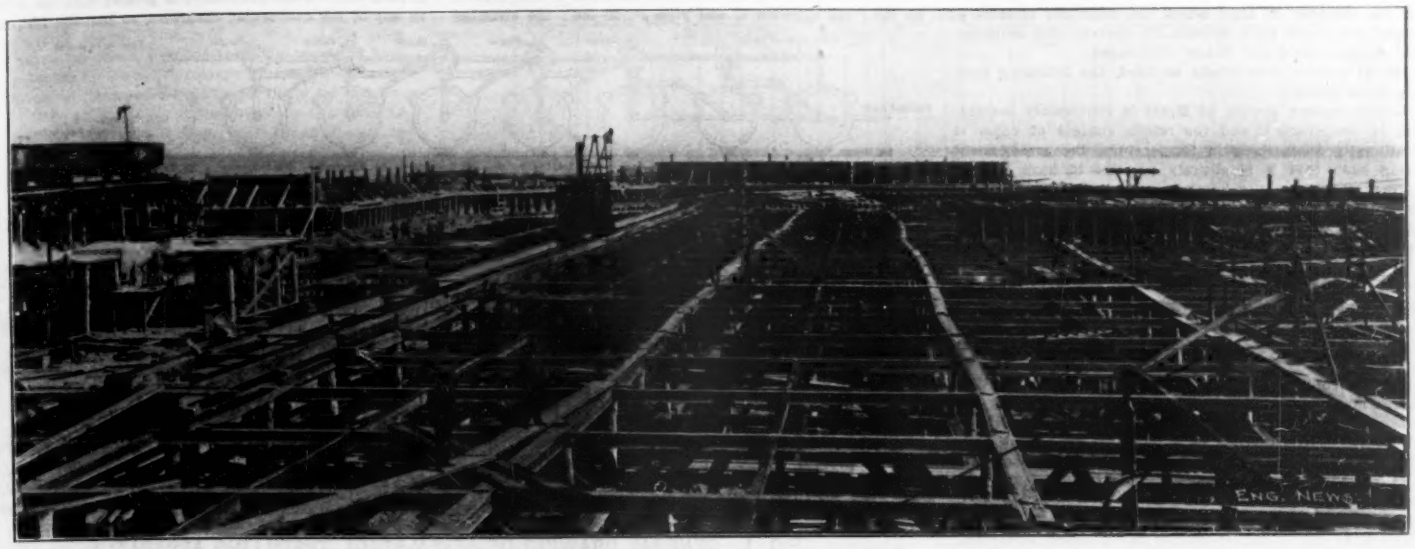


FIG. 2. COFFERDAM PUMPED OUT AND TIMBERING COMPLETED.

In the construction of the cofferdam, two rows of piles and Wakefield sheet-piling were put down and the space between them filled with clay. An opening was left for the exit of the floating pile driver, which drove the interior piles, the opening being protected by a temporary breakwater. The interior piles were driven at about 16 ft. centers, and connected by cap timbers at the water surface. Fig. 1 shows this stage of the work, with the piling and caps in place; at the right is a dredge depositing clay filling along the cofferdam, and a traveling crane is also in position. At the left is an elevated track for the delivery of material for the concrete.

After the piling and top timbering had been completed and the opening closed, the water was pumped out to a depth of about 9 ft., and another set of timbers put in place, together with inclined braces. The water was then all pumped out, and excavation commenced. This stage of the work is shown in Fig. 2, and it will be noted that some of the lines of timbers are reinforced by planks fitted against the sides of the timbers. At the left is the elevated track and the platform for the concrete-mixing machinery. Tracks are laid across the timbering to carry the concrete buckets. The timber wall along the left side and end of the cofferdam is to protect the work from the spray of the waves.

Fig. 3 is a view in the bottom of the cofferdam, showing the two rows of horizontal timbering between the piles, with the work of excavation in progress. At the left is one of the buckets used, while in the middle and at the right are two of the narrow-gage cars.

This work is being done under the supervision of Mr. F. W. Blocki, Commissioner of Public Works, and Mr. W. S. MacHarg is Consulting Engineer for the Intercepting Sewer System. The contract for the cofferdam and concrete work of the foundations of the pumping station was let to the Lydon & Drews Co., of Chicago, which company is now succeeded by the consolidated firm known as the Chicago & Great Lakes Dredge & Dock Co.

A SERIES DISTILLING APPARATUS OF HIGH EFFICIENCY.*

By W. F. M. Goss,† M. Am. Soc. M. E.

This apparatus is designed to purify water or other liquids by distillation. It can be used, also, in the concentration of liquids carrying solids in solution, the recovery of which is desired. It consists of an arrangement whereby the supply of liquid to be evaporated passes through a succession of chambers, in each of which it is gradually raised in temperature, and in all but the first of which a portion of the supply is vaporized, the process continuing until all has been changed to vapor. Heat is supplied the system at the chamber having the highest temperature only from which vapor starts in a return circulation, that generated in one element of the apparatus serving as the source of heat for the element next lower in temperature, the liquid steam increasing in volume as it passes the successive elements until, finally, all is discharged from the chamber of lowest temperature. The liquid thus discharged is entirely the result of condensation. An apparatus embodying this conception, designed to distil 500 gals. of water an hour with an efficiency of approximately 60 lbs. of water per pound of coal, is shown by Fig. 1, and a section of a single element entering into its construction, by Fig. 2.

*A paper presented before the American Society of Mechanical Engineers at its annual meeting, New York, December, 1903.

†Dean of the Schools of Engineering, Purdue University, Lafayette, Ind.

The water to be evaporated is delivered into the bottom of the chamber A, and is gradually heated by contact with the central tube as it arises to the top, from which point it passes to the bottom of the chamber B. Here its temperature is further increased and a portion of it is vaporized, the remainder being taken up bp the pump F^1 and delivered to the chamber C, of higher pressure, where its temperature is further increased and where another portion is vaporized. That not vaporized in C is taken up by pump F^2 and delivered to chamber D, which is under a still higher pressure, where it is entirely vaporized. The return circulation begins with the vapor given off in the chamber D, which passes off by the pipe J and becomes a source of heat for the chamber C, being condensed by the time it reaches the

FIG. 3. INTERIOR OF COFFERDAM.

The action of the apparatus may be best described in connection with the diagrammatic sketch Fig. 3. Several chambers A, B. C and D, each containing a central tube, are connected by suitable piping. The first chamber, A, is entirely filled with liquid and constitutes a preliminary heater. The remaining chambers, from B to D inclusive,

bottom of chamber C. From this point it is conveyed to the reducing pressure valve L, where its pressure is reduced to the pressure of the vapor within the chamber C. From L the stream passes on to the mixing valve M, where it intermingles with the steam delivered from the chamber C, the combined stream of liquid and vapor passing through the central tube of the chamber B, serving as its source of heat, being condensed to liquid form and, finally, being delivered to the reducing valve L^1, where its pressure is again reduced, and from which point it passes to M^1, where it mingles with the vapor given off by the chamber B, after which the combined streams of vapor and liquid pass through the central tube of chamber A, are cooled and finally discharged.

In the process thus briefly outlined, the following facts are to be noted:

a. The ingoing stream of liquid is continually increasing in temperature, and the return current of vapor is continually diminishing in temperature, the arrangement being such that it is entirely possible to have a fixed difference between the heating medium and the medium to which heat is imparted throughout all portions of the apparatus; also, each particular portion of each element retains a fixed temperature.

b. The losses of heat which occur from the apparatus are those of radiation and those which are represented by the differences in the temperature or condition between the liquid supplied and the condensate delivered. Heat thus lost must be supplied from the source of heat and nothing more.

c. It is conceivable that the temperature of the discharge may be so reduced as to approach very nearly the temperature of the supply; also, that as ideal conditions are approached, radiation losses may be diminished, and, at the limit, losses on both of these accounts cease; that is, the cycle of the apparatus is one of maximum efficiency.

For satisfactory operation, the total range of temperature to which the apparatus is subjected is divided

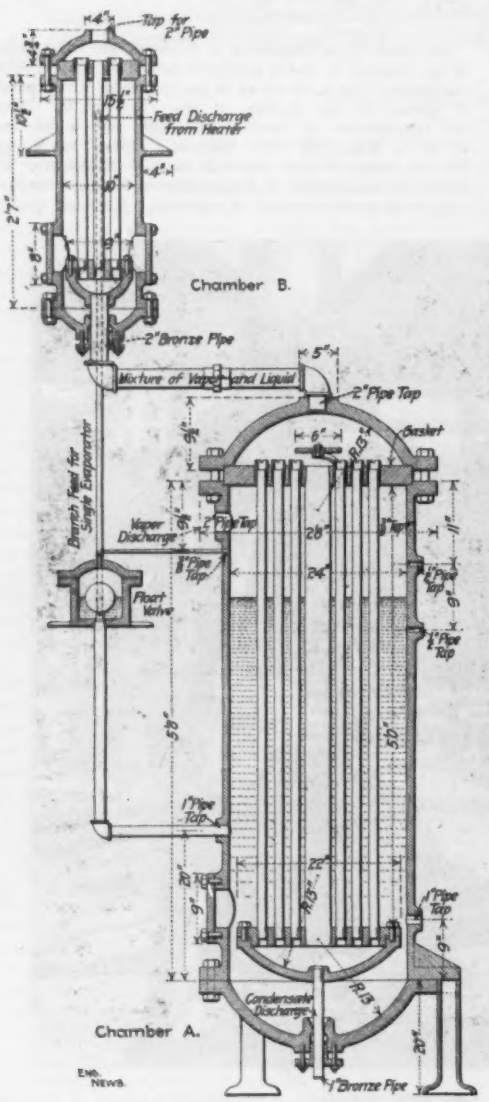


Fig. 2. Section of Single Element.

equally between the several stages of the process, the temperature of each chamber being controlled by the pressure which is maintained upon it, which in turn is regulated by valves on outlets. For example, if the apparatus shown diagrammatically by Fig. 3 is assumed to be operated from a temperature of 360° in the boiler H, to a final temperature in chamber B of 212°, then the temperature of the water in chamber C would be maintained at 262°, and that of the water in chamber D at 312°, the difference in temperature for each transmission being in this case 50°. This value also measures the difference in temperature between the mixture within the central tube and the liquid around the same in each chamber. The pressures upon the several chambers, etc., assuming the liquid operated upon to be water, would be, for the boiler H, 145 lbs.; the chamber D and pipe J, 65 lbs.; the chamber C and pipe J^1, 25 lbs.; the chamber

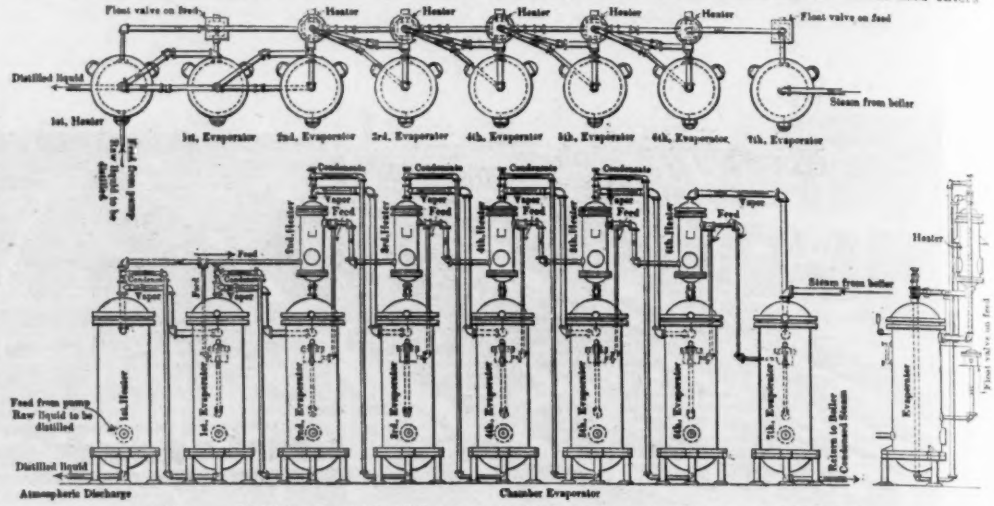


FIG. 1. GENERAL DRAWING OF SEVEN-STAGE DISTILLING APPARATUS.

B and pipe J^2, atmosphere; the pressure in each case being controlled by valves upon the discharge pipe.

The action thus far described in general terms is susceptible of careful analysis, some of the results of which appear in Fig. 4. This figure is a diagram of a five-stage apparatus, upon which are noted the pressure, temperature and condition of mixture of the circulating streams in their course through the system; also, the weight of mixture transmitted from one chamber to another for each pound of vapor delivered by the chamber of highest temperature, F. Other assumptions underlying the values given are as follows:

a. That the liquid distilled is water.

b. That the difference of temperature between each step in the process is 33°; that is, that the temperature of each succeeding chamber is 33° higher than that of the chamber next below, from which it follows that in any given element the temperature within the central tube is 33° higher than the temperature of the surrounding liquid.

c. That the temperature of water supplied is 62°.

d. That the discharge from A is at atmospheric pressure; that is, at a pressure of 15 lbs., absolute, and a temperature of 213°.

e. That 2% of the heat supplied each chamber is lost by radiation.

A more detailed presentation of analytical results is reserved for later paragraphs, but it may here be noted that the efficiency of the apparatus depends upon the number of chambers employed, and that its characteristic feature is to be found in the fact that it so conserves the heat supplied it that the process may be successfully extended through a long series of steps.

Considering now the details of the apparatus, it is to be observed that the process thus far described involves a separate pump for each of the several evaporator chambers. Thus, in Fig. 3, there are provided for the evaporator chambers B, C and D the pumps F, F^1 and F^2. This necessity arises from the fact that at each stage the feed is passing from a lower to a higher pressure, and the requirements of the cycle necessitate that the water supplied to each pump shall have the temperature of the chamber next below before being forced to the succeeding one. While this requirement is not serious when the number of evaporator chambers is small, it leads to objectionable complication when the series is extended. In the practical working out of the design, therefore, a system of feeding is employed which allows the use of a single pump, without impairing the thermodynamic cycle, the modified arrangement being inferior to that already described only in the fact that it adds slightly to the mechanical work necessary to move the feed. Its single feed-pump delivers water at a pressure sufficiently high to supply all evaporator chambers, including that of highest pressure. Water delivered by the pump is passed through a succession of heaters connected with the evaporator chambers in such a manner that the feed emerging from each heater has the same temperature as it would have had if it mingled with the water of the chamber, while branch pipes are employed to convey the feed to each individual chamber. The course of the piping in its external appearance is shown by Fig. 1. It will be seen that the feed enters the base of the preliminary heater, is delivered therefrom at a point near the top, is conveyed to a small heater over the second evaporator chamber, thence to the heater over the third evaporator chamber, and thence on to the last heater over the sixth evaporator chamber. Branches are taken off after each heater to supply the evaporator chamber with which the heater is connected. The control of this supply is best indicated by Fig. 2, showing the float-valve regulating the admission of water to the evaporator chamber. It will be remembered that the pressure above the float-valve is greater than the pressure in any of the evaporator chambers, so that the feed enters whenever the valve is off its seat. Referring more particularly to the heater (Fig. 2), it will be seen that this is similar in construction with the main evaporator chamber. The mixture of vapor and liquid which is to supply heat to the main evaporator chamber first passes through the tubes of the heater, the feed water circulating around the tubes.

Concerning the maintenance of the apparatus, it should be observed that the boiler from which the heat is supplied (Fig. 3, H) is subject to a closed circulation. No renewal of water is required, and hence there can be no trouble at this point from incrustation. Concerning deposits of solid matter in other portions of the system, it is to be noted that only distilled water and vapor circulate within the tubes (Fig. 2). This is true of the heater as well as of the evaporator chamber. The solid matter which may be deposited within the chamber around the tubes may be disposed of by use of a blow-off, by cleaning through manholes, or by the complete removal of the nests of tubes from the shell of the chamber. In the construction of the apparatus the central tube is threaded to the tube-plate at both ends. All other tubes are threaded at their lower ends only. The presence of the central tube maintains the relative position of the tube-plates and permits all the tubes of a chamber to be withdrawn together.

Having defined the character of the apparatus, attention

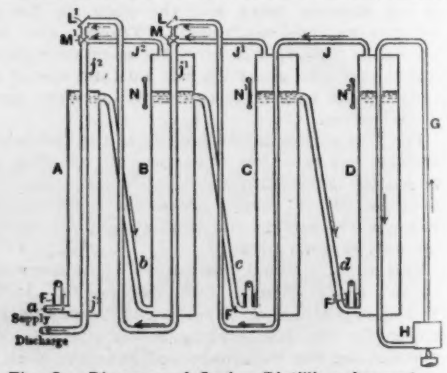


Fig. 3. Diagram of Series Distilling Apparatus.

may be given to matters affecting its performance. In general, three different classes of the apparatus are to be deal with, and for convenience Class A will be designated as representing an apparatus all portions of which are operated at pressures above the atmosphere; Class B as representing an apparatus all portions of which are to operate below the pressure of the atmosphere, and Class C as representing an apparatus a portion of which is to operate at pressures above the atmosphere and a portion at pressures below the atmosphere. Class A may be regarded as a high-pressure apparatus, Class B a low-pressure apparatus such as might be operated by the use of exhaust steam, and Class C a high and low pressure apparatus. Practical and convenient ranges of pressure and temperature applying to each of the three

classes thus designated, when designed for the distillation of water, are as given in Table I.

TABLE I.

Class.	Designation—As to pressure.	Absolute pressure, lbs.—Highest.	Absolute pressure, lbs.—Lowest.	Temperature, degs. F.—Highest.	Temperature, degs. F.—Lowest.
A	Pressure: High...	115	15.0	338	212
B	Low	15	1.0	212	102
C	High and low.	115	1.0	338	102

The relations shown are merely chosen for purposes of illustration. So far as the working of the apparatus is concerned, any other practical limits might have been chosen.

The weight of water which will be distilled for each pound of saturated steam supplied from the source of heat for an apparatus of the high-pressure type, working under the conditions of pressure set forth in Table I., and assuming no loss to occur by radiation or in the form of vapor from the delivered stream, will be as shown in Table II.

TABLE II.—Weight of Distilled Water per Pound of Dry Steam Used.

No. evaporator chambers.	Lbs. water per lb. of steam.	No. evaporator chambers.	Lbs. water per lb. of steam.
3.....	2.8	7.....	5.9
4.....	3.6	8.....	6.5
5.....	4.4	9.....	7.1
6.....	5.2	10.....	7.6

The weight of water distilled for each pound of steam supplied is nearly the same for all three classes as above defined. An approximate relation applying to all classes is represented by the formula, $W = 0.85\ N$, in which W is the number of pounds of water distilled for each pound of steam supplied, and N is the number of evaporator chambers. If the boiler which serves as the source of heat delivers 10 lbs. of steam per pound of coal burned, the output of distilled water per pound of coal will be ten times the values given in Table II.

Results appearing in Table II. are in some cases subject to correction to cover losses due to the presence of vapor in the discharged stream. In the action of the machine, all condensation is the result of the cooling action of the incoming stream of liquid feed. Under certain conditions, this will be insufficient, in which case a portion of the issuing stream delivered from the apparatus will be vapor and will in part disappear as it emerges from the pipe. The extent of this loss, if any, decreases as the number of chambers is increased. In apparatus of the Class A it entirely disappears when seven evaporator chambers are used; but in types B and C there will be a slight loss even when as many as ten evaporator chambers are used. The percentage of the total weight of the discharged stream which will be delivered in the form of vapor is given in Table III.

TABLE III.—Percentage of Discharge Steam Lost By Vaporization

Number of evaporator chambers.	Class of apparatus. A.	B.	C.
3	21%	33%	32%
4	11%	25%	22%
5	6%	19%	16%
6	2%	16%	12%
7	0%	13%	10%
8	0%	11%	8%
9	0%	9%	7%
10	0%	8%	6%

The extent of heating surfaces in each element (one evaporating chamber and its attached heater) needed for a given capacity is not materially affected by changes in the number of elements in the series. Assuming the pressure ranges set forth in Table I., and assuming each foot of tube surface to transmit 400 thermal units per degree difference of temperature per hour, there will be required in each element of an apparatus designed to distil 1,000 gals. of water per hour an amount of heating surface as given in Table IV.

TABLE IV.—Required Amount of Tube Surface in Each Element per 1,000 Gallons of Water to be Distilled.

Class of apparatus.	Tube surface.
A—(High pressure)	174 sq. ft.
B—(Low pressure)	188 "
C—(High and low)	113 "

The total amount of tube surface required for any apparatus of the capacity stated will be found by multiplying the number of evaporator chambers it is to contain, plus one, by the value assigned its class in the preceding statement. The unit added covers the large heater (1st Heater, Fig. 1). For example, if it is required to design a seven-chamber apparatus of the A class to distil 1,000 gals. of water per hour, then the total number of square feet of heating surface for the whole system will be 8×174 or 1,392 sq. ft.

The size of the small feed-water heaters varies with the quantity of water which each must handle, and this diminishes with each step that the feed is advanced, the percentage of the total feed handled by each heater being as given in Table V.

TABLE V.—Percentage of the Total Feed Passing Each Heater.
(Numbers assigned heaters agree with those given in Fig. 1.)

No. of evaporator chambers in series.	Designation of heater. (Numbers of heaters one less than number of evaporators) 1.	2.	3.	4.	5.	6.	7.	8.	9.
1	100	..	..	..	..	..	..	..	..
2	100	..	..	..	..	..	..	..	..
3	100	71	..	..	..	..	..	..	..
4	100	76	53	..	..	..	..	..	..
5	100	81	63	44	..	..	..	..	..
6	100	84	70	54	37	..	..	..	..
7	100	85	75	62	48	33	..	..	..
8	100	86	75	64	52	40	27	..	..
9	100	86	78	68	58	48	37	25	..
10	100	90	81	72	63	53	43	33	23

From the values in Table V., and the known capacity of a proposed apparatus, the weight of water in pounds which will pass each heater can be ascertained, after which the tube surface of each small heater may be found by use of the following formula, $A = 0.00173\ W$, in which A is the required area of tube-surface in the heater and W is the number of pounds of water passing the heater per hour. On the basis of this formula, it can be shown that the area of tube surface for the several small heateers of a seven-stage apparatus, designed to distil 1,000 gals. of water per hour, under the pressure range of Class A, Table I., should be as given in Table VI.

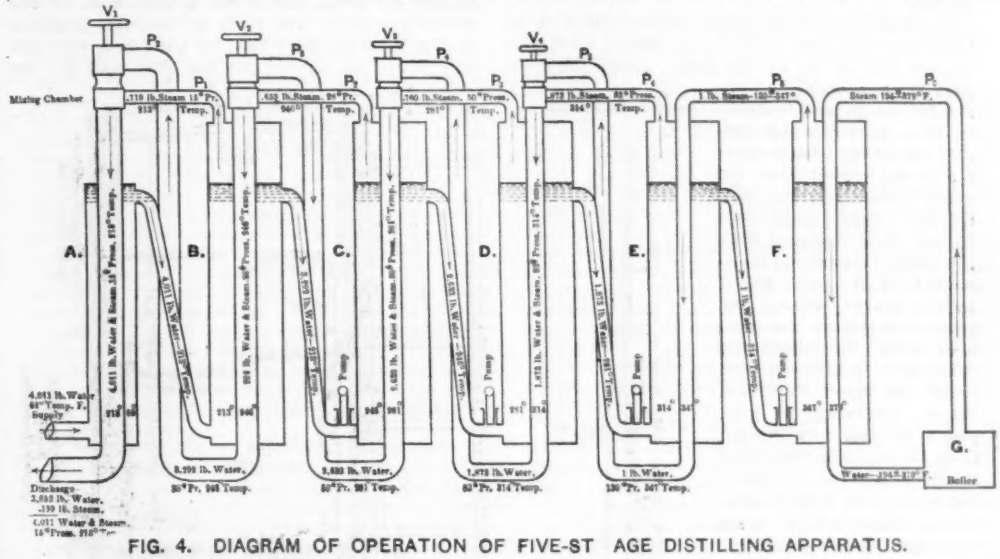


FIG. 4. DIAGRAM OF OPERATION OF FIVE-ST AGE DISTILLING APPARATUS.

TABLE VI.—Required Amount of Tube Surface in Small Heater.

Designation of heater.	Heating surface.	Designation of heater.	Heating surface.
2d	4.8 sq. ft.	5th ...	10.6 sq. ft.
3d	6.8 "	6th ...	12.4 "
4th	8.8 "		

This will serve to indicate the significance of the small heater as a part of the general design. Since all are relatively small, the action of the apparatus as a whole can not be greatly affected if all are made the same size. If in the preceding example all were made equal to the mean value obtained by calculation, the surface of each would be 8.6 sq. ft., and the area assigned the several evaporator chambers (Table IV.) may be reduced by a like amount.

Having now determined the proportions which must be given the several members of the apparatus, it should be stated that the arrangement can not always be that set forth in Figs. 1 and 2. In a low-pressure system, or in a high-and-low pressure system (classes B and C), some modification in the mechanical arrangement shown by the diagrams is necessary. Thus, the chambers which are low in the scale of pressures must be so arranged that the water of condensation from one chamber will flow freely to the chamber next lower in pressure. That is to say, it will be necessary to place one element above the other. The reason for such an arrangement is that the pressure difference between each chamber is not sufficient to overcome the head of water equivalent to the distance from the bottom of one chamber to the top of the next. Just how many chambers will need to be so arranged can only be stated when the conditions of the individual case shall have been defined. Obviously, the cycle will not be interfered with or the working of the apparatus changed if all the elements are arranged in a vertical series instead of a horizontal series.

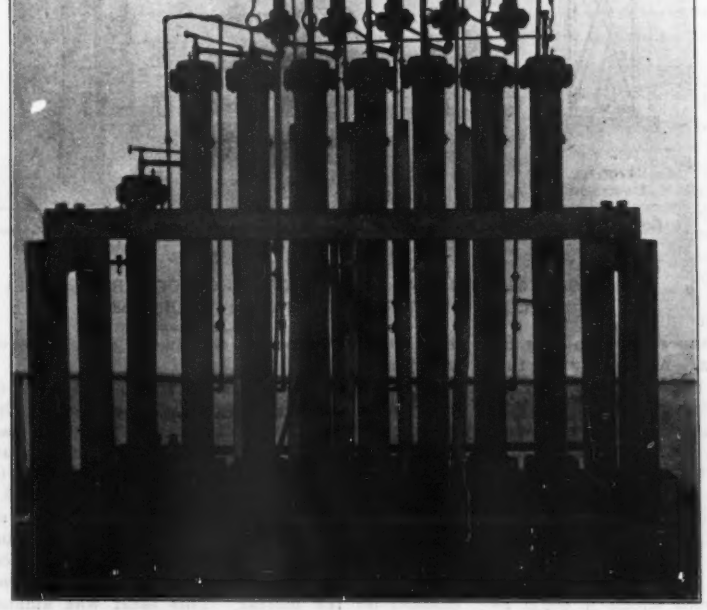


FIG. 5. VIEW OF EXPERIMENTAL SEVEN-STAGE DISTILLING APPARATUS.

To the foregoing should be added the fact that the practicability of the cycle described has been well established by the performance of a small seven-chamber apparatus, which is shown by Fig. 5. The view makes the machine appear more complicated than it really is, since the heaters are made up of pipe fittings. It shows also the apparatus with most of the covering removed, whereas in service all portions of the machine were covered with non-conducting material. By the aid of this apparatus it has been shown that vaporization takes place and the whole section proceeds as has been described, even when the temperature difference between adjacent chambers is less than ten degrees, and by its use facts already presented, with reference to capacity and efficiency, have been substantially checked.

CONCRETE-STEEL COLUMNS FOR REINFORCING AN OLD BUILDING.

By Keith O. Guthrie.*

The 10th St. Station of the Louisville Lighting Co. was built about ten years ago of brickwork laid entirely in lime mortar. In time this mortar became so dead that it was possible to lift a brick from its bed by hand. This deterioration,

*Engineering Department New York Edison Co., 53 West 130th St., New York City.

together with excessive vibration through the upper part of the building, which rests on piles, came to call for some measures of strengthening. To save the cost of entire rebuilding, the following method of reinforcement by concrete-steel columns was devised and carried out by the writer.

The walls are 26 ins. thick for the first 8 ft. to main floor; 17 ins. for 18 ft. to second floor, and 13 ins. for 26 ft. to the roof. Above the main floor the side walls had pilasters, inside and outside, on 16-ft. centers which carried the 15-in. I-beam girders of the second floor, the crane beams and the roof-trusses. These piers, 26 × 26 ins., were removed from the walls, leaving the intermediate wall-panels intact. In the spaces which had been occupied by the piers were built the monolithic columns of reinforced concrete. As shown by Fig. 1, before removing a pier, heavy shoring was erected from the concrete basement footing to the roof, supporting floors and roof-trusses.

The division-wall piers were cut out from light staging on top of the boilers and from the boiler-house roof. The cutting on the front wall was done from a light working scaffold 4 × 6 ft. and 50 ft. high, which was taken down and moved about from one point to another at a cost of $2.94 for each set up. The 12 cu. yds. of brickwork in a pier were cut out by two men with stone-drill and sledge in about 15 hours. The total cost was $8.36, or $0.70 per cu. yd., including removal to the street.

After cutting out a pier the joints in the wall-ends were chinked out clean of mortar and brushed to give a good bond with the concrete. Then the reinforcing bars were set up. There were eight of these, four on a side, of 2 × ⅜-in. common iron, costing 2c. per lb. Fifteen foot lengths were used, spliced with 2¾-in. bolts. These bars were distanced by side-bars and cross-bolts at the splices. A cage was thus formed which, while not self-supporting for its full length, was easily kept in place.

For hoisting the concrete, a yard-arm, extending from the roof about 2 ft. and carrying a large single block, was used. Through this ran a 1½-in. line, one end having a hook for catching the concrete buckets and the other leading through a snatch-block at the ground to a mule. This mule, rented for $1 a day, with man leading at $1.50, hoisted concrete for from 25c. to 40c. per yard, depending on the speed with which it could be handled inside the column. I believe that in continuous work, with rapid unloading, a good mule at $1 a day led by a boy at 75c. could hoist material an average of 50 ft. for 7c. or 8c. a ton, or 15c. a yard for concrete. As we found, however, a good deal depends on the mule.

Concrete was mixed at the foot of each column by usually three men, with a fourth turning over and filling the buckets. Another man received the buckets on the working scaffold at the level of the concrete and emptied them into the mold. A very faithful old negro stayed inside the mold all the time, tamping with a short iron bar, with hands and with feet—all accompanied by singing quite original with himself. The buckets were made of galvanized iron, heavily strapped across the bottom and around the top, and cost 90 cts. apiece. They were 12 ins. in diameter and 16 ins. high—just about what a man could handle full of concrete.

Batches of 6 cu. ft. were mixed which raised the level in the column about 15 ins. After tamping each batch, the man inside the form hooked six cross ties of No. 6 steel wire on the reinforcing bars. The form of these ties is shown in Fig. 2. They were bent by hand in a vise and cost about 1c. apiece for the wire and 1c. for the labor of forming; 130 were used in each column.

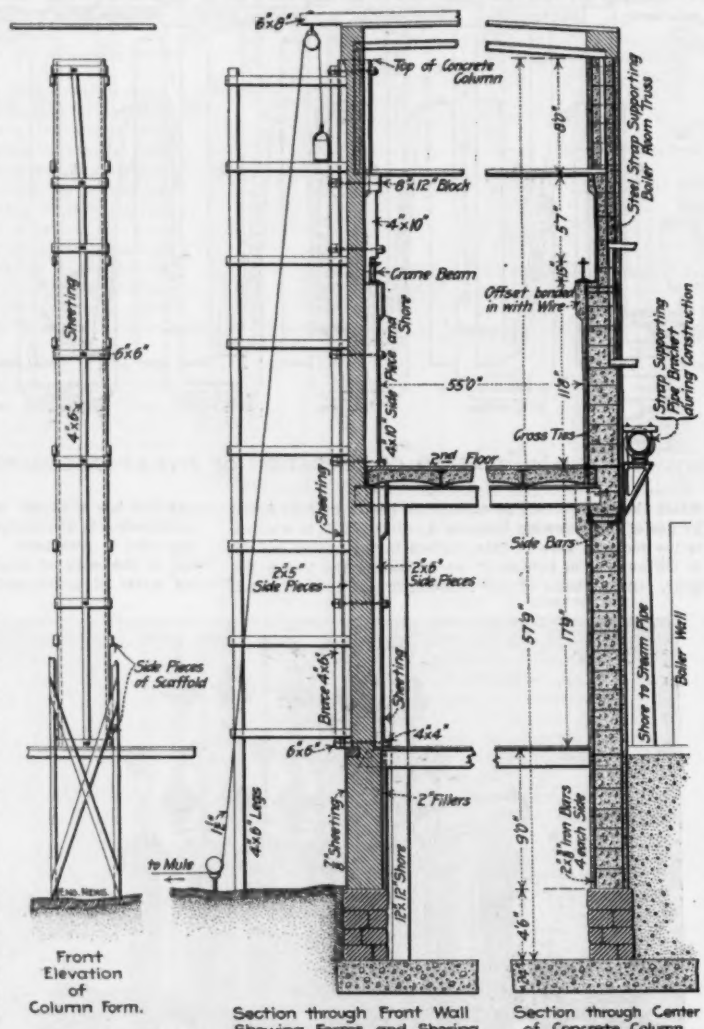


FIG. 1. SKETCH SHOWING CONSTRUCTION OF CONCRETE-STEEL COLUMNS FOR REINFORCING OLD BUILDING.

It took from one and a half to two days to concrete a column containing 12 cu. yds. The work could have been done in half the time had the man inside been able to handle the material. The mixture used was 1 part Helderberg Portland cement; 3.8 parts Ohio River sand, and 5.7 parts limestone "binder." It was deposited wet enough to be easily pushed into the various corners, around beam ends. A very good surface was obtained except where leaks in the form drained off the mortar. This fault was almost entirely obviated on the straight outside pilasters by the use of triangular molding strips, tacked into the corners. They were of soft wood, poplar, 1½ ins. on a side, and made the corners watertight. Another advantage in their use lay in the fact that a beveled corner comes out more smooth and even than a square one. The columns were painted after completion with neat Portland cement—put on thin with a white-wash brush.

The work furnished a striking test of the ability of good cement to set under vibration. After removing the brick pier and before concreting, the walls at that point would shake viciously from the vibration of high speed horizontal engines. The soft concrete took some of this out, however, on the day it was put in, by virtue of the reinforcement. Then as the cement took hold the columns became quite stiff with only a tremor in place of the vibration.

Mostly colored labor was used on this and other work at the same station, and, as a rule, was quite faithful and efficient except that men kept too long were spoiled and came to "need a vacation."

A very close account of costs was kept, which is summarized in the accompanying table, taking one of the outside columns as a unit and using averages for the six columns of that wall.

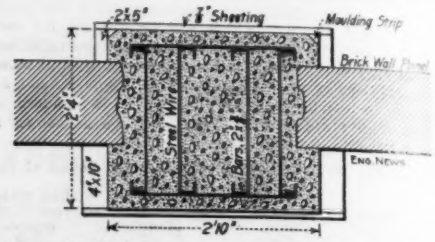


Fig. 2. Cross-Section of Concrete-Steel Column for Reinforcing Old Building.

Table Showing Average Cost for One Concrete-Steel Column for Reinforcing Old Building.

(All labor, 15 cts. an hour; foreman (who worked), 22½ cts. an hour.)

	Cost.	Totals.	Unit costs.
Shoring floors and roof—labor..	$5.87		
As above—lumber used 3 times.	3.44		
Total for shoring		$9.31	
Concrete forms:			
Setting up and removing....	$11.32		
Material	4.81		
Total for forms		$6.13	$0.51 a yd.
Working scaffold, 50 ft. high..	$2.94		
Cutting out brick and removing	8.36		.70 "
Resetting mixing board and rigging hoist	1.62		
(8) 2-in. × ⅝-in. iron bars—1,034 lbs. at 2 cts. a lb....	20.68		
Drilling iron bars in station...	1.44		
Setting in place iron bars.....	1.23		
Bolts for splicing and spacing.	3.98		
No. 6 wire used for 130 cross-ties at 2½ cts. a lb.....	1.39		
Labor of forming same.....	1.13		
Total for reinforcement, 1% area column		$29.85	.029 a lb
Concrete:			
Cement ....10.17 bbls., $2.40	$24.40		
Sand ..... 5.87 yds., .90	5.28		
Stone ..... 8.75 " 1.25	10.94		
Total for material		$40.62	3.38 a yd.
Mixing, wheeling, etc.	$15.73		
Hoisting by mule ,with driver..	4.80		
Handling bucket on scaffold ...	2.93		
Tamping inside column.....	2.93		
Total labor for handling....		$26.39	2.20 "
For concrete, labor and material.	67.01		5.58 "
For concrete, 1% reinforcement..	96.86		8.07 "
For concrete forms added in....	102.99		8.58 "
Miscellaneous.			
Painting*	$3.89		
Clearing away rubbish, etc.....	1.97		
Tools	.59		
Rigging, etc.	2.64		
Total, miscellaneous items..		$9.09	
Total for 1 complete column.....		$144.31	$12.03 a yd.
For 6 columns of wall.....		865.86	
For 6 columns other wall.....		992.14	
Grand total, 12 columns....		$1,858.00	

*Both sides with cement and general finishing.

Note.—The increased cost, $10.52 a piece, for the columns of the division wall was due to the complications of steam piping and the boiler room roof trusses.

INTERURBAN ELECTRIC TRACTION SYSTEMS; ALTERNATING CURRENT VS. DIRECT CURRENT.*

By P. M. Lincoln,† M. Am. Inst. Elec. E.

Practically all the electric railway work in America has been done by direct current. The alternating current traction system, although it has received considerable attention from American engineers, has not until recently been favorably considered by them. In Europe, on the other hand, the alternating current traction problem has received a large amount of attention. The polyphase induction motor has been developed by European engineers for traction purposes and a number of installations have been made in Europe with apparatus of this character. American engineers have consistently refused to adopt the polyphase induction motor for traction purposes on the ground that it is not suitable for that purpose. The principal reasons for this stand are two in number.

First, the polyphase induction motor is inherently a constant speed motor and therefore not adapted to traction purposes. Continual change of speed is one of the characteristics of traction work. The direct current series motor is peculiarly adapted to this class of work because it is inherently a variable speed motor. At one definite speed the polyphase motor is an efficient machine, while

*From a paper read before the Electrical Section of the Canadian Society of Civil Engineers.

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at all other speeds the efficiency cannot be greater than the ratio of the actual speed to the synchronous speed. For instance, if the actual speed at which a given induction motor is working is 10% of its synchronous speed, the power utilized is at most only 10% of the power put in. In traction work a large part of the work done is necessarily at speeds below the maximum attained and at these lower speeds the maximum economy that can be obtained from induction motors is necessarily small.

One expedient used by European engineers to reduce this source of loss is the use of motors in concatenation or in tandem; that is, the secondary of one motor is fed into the primary of another on the same car. If the pair of motors thus concatenated are wound for the same number of poles, this expedient has the effect of making the synchronous speed of each of the pair of concatenated motors half that which it is when not in concatenation. It is equivalent in direct current practice to throwing two shunt motors in series. Up to the half speed point, therefore, there is a gain of economy by this arrangement. By winding the two concatenated motors for different numbers of poles, more than one point of maximum economy can be secured between zero speed and full speed, but this arrangement has the disadvantage of being able to use but one-half the total motor capacity above half speed, while the greatest expenditure of energy takes place above half speed. In order to secure the advantages of concatenation, however, it is necessary to add largely to the weight of the electrical apparatus. European practice has been to equip cars with four motors, two main motors and the other two being used only while the car is below half speed. Above half speed these latter two motors are running idle and are doing no useful work. The energy required to take care of the additional weight is an offset against the energy which is saved by concatenating the motors. For long runs this expedient would probably be detrimental since the energy taken up to transport the extra weight would be more than equivalent to the energy saved at the start.

The second reason against the use of polyphase induction motors for traction purposes is the necessity for providing at least two overhead conductors. If the track is not used as one of the conductors, then the necessity arises of using at least three overhead conductors. Maintenance of insulation on such overhead conductors when they are at high voltage is naturally a difficult problem, more difficult than to maintain the insulation between a single conductor and ground, as would be the case in the single phase system.

American engineers, instead of endeavoring to adapt the unsuitable induction motor to traction purposes, have devoted their energies to the development of a suitable alternating current motor. The idea of using a series motor operated by alternating current is not new. The only alternating current single phase motors which have speed and torque characteristics suitable for electric traction purposes are those of the commutator type. In this type of alternating current motor the speed and torque characteristics are practically identical with those characteristics in the direct current series motor. Interurban electric traction work, such as exists to-day was not at that time thought of, and this is, in my opinion, the field peculiarly adapted to the alternating current traction system.

In considering the general problem of electric traction, the question naturally arises—what is gained by the use of alternating current over direct current; and the converse of this question also naturally arises—what is it necessary to sacrifice in order to obtain the benefit of alternating current traction?

The principal advantages of the alternating current electric traction over the direct current are as follows:

(1) Limits to trolley voltage are removed.
(2) Avoidance of rheostatic losses.
(3) The necessity for rotary converter sub-stations abolished.
(4) Manual attendance at the sub-stations done away with.
(5) Danger of electrolysis by return current avoided.

To take up these points more in detail:

(1) VOLTAGE LIMIT REMOVED.—The greatest item of cost in the electrical equipment of interurban traction systems as they exist to-day is that of secondary distribution. This item of cost is usually between 25% and 50% of the total for electrical equipment, and usually much nearer the latter figure than the former. A potential of 600 volts at the motor in a direct current traction system is practically the limit at which present designers and manufacturers are willing to guarantee their machines, except in some special cases. This necessarily limits the voltage fed into the secondary distribution system to, say, 700 as a maximum. The consequence of this comparatively low voltage is naturally a high cost for conductors of this secondary distribution. The alternating current system, providing as it does the possibility of greatly increasing the voltage of the distributing system, thus largely cuts down its cost.

Another point which militates against the use of direct current is the fact that when large units are used it is difficult to collect the large amount of current for their operation. For this reason, as well as an advantage in cost, trolley construction has been largely replaced by the third rail for interurban work. By raising the voltage of the secondary system, however, the current taken by a locomotive may be reduced and consequently the difficulty with collecting devices may be made to disappear.

(2) RHEOSTATIC LOSSES AVOIDED.—In the direct current system the voltage at the car is practically constant and while the counter E. M. F. of the motors is building up, the excess voltage must be taken up by resistance. At the start, therefore, a comparatively large rheostatic loss occurs. With the alternating current system, on the other hand, the voltage at the car may be controlled by suitable means and the rheostatic loss thus avoided. When stops are few and consequently runs are long, the rheostatic loss in the direct current system is a small proportion of the total, and therefore under these conditions this advantage of the alternating current system is not so greatly marked. With short runs, on the other hand, and consequently frequent starts, the rheostatic loss with the direct current system amounts to a considerably greater proportion of the total loss and the alternating current system therefore has a greater advantage.

(3) NECESSITY FOR ROTARY CONVERTERS AVOIDED.—The cost of sub-station equipment constitutes one of the large items in the cost of the electrical equipment of an interurban road. In this sub-station equipment by far the largest item of cost is the rotary converters. In the alternating current equipment the rotary converter has no place, thus avoiding not only a large item of cost, but also one of the largest items of the loss of power.

(4) ATTENDANCE AT SUB-STATIONS DONE AWAY WITH.—The direct current rotary being a piece of revolving machinery, of course requires manual attendance at the various sub-stations. Alternating current sub-stations consist of static transformers only, and therefore require attendance only for the purpose of operating the switches. Making the switching devices entirely automatic in their operation avoids the necessity of attendance for this purpose. A still further refinement is the use of distant controlled switches operated from a central point, say the main power house. Electrically operated switches have already been developed to be operated from a distance of several hundred feet, and no reason exists why this distance of operation cannot be extended to 20 to 30 miles by proper design. By including in such a switch operating mechanism also a signaling device, by which the position of the switch is made known at the central point, the switch operating system becomes complete and no necessity exists for attendance at the alternating current sub-stations for any purpose except occasional inspection. There is of course an expense in connection with installing such a system of operating switches electrically, but it bears no comparison to the expense of manual attendance.

(5) ELECTROLYSIS.—Electrolysis of parallel conducting systems is generally recognized as one of the most serious dangers in connection with present direct current trolley systems, and the fact that an alternating current system avoids this danger entirely need only be mentioned in order to be recognized as a marked advantage.

So much for the advantages which accrue to the alternating current system. Now the question arises—what points must be sacrificed in order to obtain these advantages. The disadvantages which necessarily accompany the use of the alternating current traction system are as follows:

(1) Additional weight.
(2) Difficulty of operating on existing lines.
(3) Increased rail loss.
(4) The fact that an active E. M. F. exists between field turns.
(5) Possible interference with telephones.

We will take up the above points in detail.

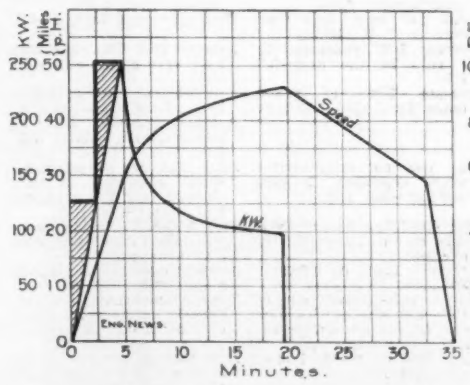


Fig. 1. Typical Two-Mile Run Curve of Electric Car Equipped with Direct Current Motors.

Weight of car, 35 tons.
Wheels, 36-in.; gear ratio, 21:50.
Equipment: Two No. 50 C. direct current motors.
Schedule speed: 30 miles per hour.
Average volts at motor, 550.
Average KW., 67.2.
$\sqrt[2]{\text{mean}^2}$ current per motor, 105 amp.
Acceleration: 1 mile per hour per second.
Brake retardation: 2 miles per hour per second.

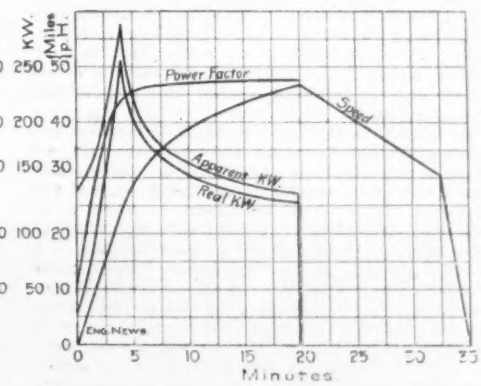


Fig. 2. Typical Two-Mile Run Curve of Electric Car Equipped with Alternating Current Motors.

Weight of car, 41.3 tons.
Wheels, 36-in.; gear ratio, 17:53.
Equipment: Two 165-HP. A. C. motors.
Schedule speed: 30 miles per hour.
Average volts at motor, 200.
Average KW., 73.9 real; 84.7 apparent.
Acceleration: 1 mile per hour per second.
Brake retardation: 2 miles per hour per second.

(1) ADDITIONAL WEIGHT.—An alternating current motor of a given capacity is necessarily somewhat heavier and somewhat more expensive than a direct current motor for the same capacity. This difference in the motor, however, does not constitute the total difference in weights of equipment. In order to make use of the advantages of high trolley voltage, the alternating current equipment should preferably be provided with a step-down transformer on the car. Also, in order to obtain the advantages of avoiding the rheostatic losses, some provision must be made for controlling the voltage on the car. The transformer, the voltage control apparatus, and the greater weight of motors make the alternating current equipment necessarily heavier than the direct current.

One of the most attractive methods for controlling the voltage on the motors is the use of an induction regulator. The principal advantage over other forms is that it does not require the interruption of the current and is therefore of particular advantage in large equipments. It is this problem of breaking the current that forms not only the greatest difficulty with direct current equipments of large capacity, but also one of the largest items in the deterioration account. The induction regulator has the disadvantage of adding considerably to the weight and in equipments of comparatively small size where the difficulty of current interruption is not great will probably be replaced by some other method of voltage control, such as loops or commutated coils on the step-down car transformers.

(2) DIFFICULTY OF OPERATING ON EXISTING LINES.—Practically all interurban roads run in and through cities on existing tracks, and therefore must use the existing sources of direct current power. In order to meet this condition the equipment for an alternating current interurban road must be so arranged as to operate on alternating current outside the city and on direct current inside. Although this is entirely possible, it must necessarily prove to be a matter of considerable complication. It means in the first place the use of motors which can be operated from both direct and alternating current. This is entirely possible with the series alternating current motor. It means in the second place that another system of control must be added to the car. This objection might in part be avoided by using rheostatic control for both the alternating current and direct current conditions, but the objection obtains that this method will deprive the alternating current system of its advantage of saving rheostatic losses. Further, means will have to be provided for disconnecting all transformers when running from direct current system and reconnecting them when running from alternating current system. All these matters, although they mean a considerable amount of complication, are entirely possible. The most important part of the equipment—the motors—can be operated from direct as well as alternating current.

(3) INCREASED RAIL LOSS.—Experiments have shown that with alternating current from 2,000 to 3,000 alternations, the actual loss which takes place with a given current through the iron rails is from three to five times that which the same direct current would give. The higher ratios of loss hold for the higher frequencies. At first thought this seems to be an important objection to the A. C. system. But when it is considered that in order to utilize the main benefit of the alternating current, a higher trolley voltage is used and, therefore, smaller currents in the return conductor, the element of rail loss in an alternating current proposition may be made even a smaller proportion of the total than in the direct current, in spite of this apparently large handicap. The rail loss with direct current is usually a small proportion of the total and this with alternating current, at the trolley

voltages which are usually considered—viz.: 2,000 to 5,000—becomes a much smaller proportion.

(4) ACTIVE E. M. F. BETWEEN FIELD TURNS.—The space that can be assigned to the motor for operating a car is necessarily limited. It is this limitation of space, in fact, which often forces the use of a four-motor equipment instead of a two-motor equipment, the available space not being large enough to allow the installation of motors, two of which are sufficient for the work. When we consider the A. C. motor, the question of space available becomes still more exacting, first because the A. C. motor is necessarily heavier and therefore occupies more space than an equivalent D. C. motor; and, second, because of the active E. M. F. that exists between the field turns in the A. C. motor, and which, other things being equal, again requires additional space for insulation. In the matter of E. M. F. between field turns, the A. C. and D. C. motors are quite different. The E. M. F. between the field turns of a D. C. motor is due simply to ohmic resistance, and a short circuit between turns simply throws out of action the turns so short circuited, and if not too severe, does not interfere seriously with the motor's operation. Between field turns of the A. C. motor on the other hand, there is an active E. M. F. similar to that between the turns of a transformer winding. A short circuit between field turns in an A. C. motor, therefore, means a destructive short circuit and an immediate interruption of service from that motor. In other words, the effect of a short circuit between field turns in an A. C. motor has the same effect that a short circuit between armature turns would have in either the A. C. or D. C. motors. Roasting out of field coils is one of the most frequent causes of trouble in D. C. motor equipments, and it is readily realized that this matter of active E. M. F. between field turns in the A. C. motor is a serious one. As an offset against this disadvantage of an active E. M. F. between field turns, the A. C. motor possesses the advantage of being capable of operation at low voltage, thereby reducing the number of turns on the series field and increasing the proportionate space for insulation. The use of a stepdown transformer on the car makes available any desired voltage at the motor. This existence of an active E. M. F. between field turns is the most serious obstacle to the use of high voltage on the motor. Even with low voltage, the A. C. motor is laboring against the handicap of occupying more space than an equivalent D. C. motor, and the use of high voltage still further increases this handicap. The limitations of space do not apply to the transformer in anything like the same degree that they do to the motor, and no particular difficulty is anticipated in building a transformer for this work.

This limitation of available space for the motor and the existence of an active E. M. F. between field turns makes it seem probable to the writer that the A. C. railway motor of the future will be operated at low voltage and will receive its current from a transformer situated on the car.

(5) INTERFERENCE WITH TELEPHONES.—It is a question whether alternating current in the rails will interfere with telephones and similar instruments more than the direct current which they have to contend with at present. In any event, the amount of current in the rails can be reduced by the use of higher voltages so that this source of interference can be made less than it is with the present direct current system. Further, means have been proposed whereby the current can be confined entirely to separate conductors provided for the purpose and not allowed to wander at will through any return circuit that may exist, as is the case with the direct current system. This can be done of course only at the expense of erecting a separate system for the return currents and a system of series transformers whereby these currents can be confined to this return system. The alternating current system therefore possesses the advantage of being able to use the rails for contact and still not allowing the alternating currents to escape at will through the earth. As a matter of fact, interference with other circuits by the alternating current system is expected to be less than with the present direct current system.

The engineer has been defined as a man who could do for one dollar what any fool could do for two. The engineer, in other words, stands for efficiency. It is he who accomplishes a given result with a minimum expenditure of effort and money. Suppose we apply this criterion to the comparison between the A. C. and D. C. systems: by which of these systems can a given service be rendered most economically? In order to answer this question, we shall assume a certain typical interurban road, ascertain the first cost by both systems and the cost of operating by both systems and compare the results. Suppose the typical road which we will assume to be as follows:

Length—60 miles.
Schedule speed—30 miles per hour, cars running half hour apart.
Number of stops—30; that is typical run, 2 miles long.
Weight of D. C. car, complete—35 tons.
Weight of A. C. car, complete—41.3 tons.

It may be noted here that the above difference in weight is not the minimum that can be obtained. A large part of the difference in weight comes, as previously stated, in the induction regulator, with which it is assumed the A. C. car is equipped. Other methods of voltage control can be applied which would be considerably lighter, but the induction regulator is selected on account of the advantages previously mentioned. The A. C. system is therefore working under a handicap which is greater than would be the case if some other method of control were assumed.

Fig. 1 shows the speed-time and KW.-hours curve of a direct-current car of 35 tons over the typical run. The equipment, gear ratio, acceleration, etc., are given on the curve.

Fig. 2 shows the same for an alternating-current typical run and in addition gives also the apparent KW. and power factor. It will be noted that the difference in power at the car is only 10% in favor of the direct-current equipment in spite of the fact that the difference in weight is 18% in favor of the direct current.

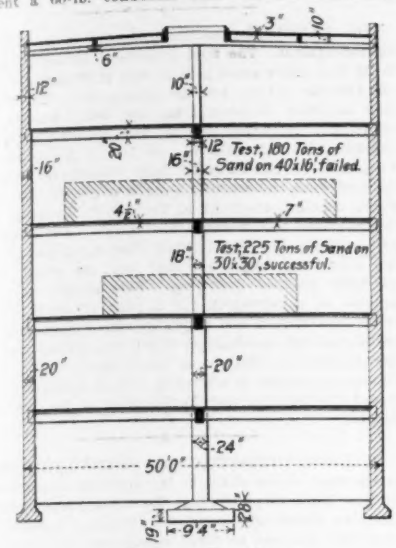
The location of the power house is assumed in both cases to be on the line of the road midway between the termini, therefore 30 miles from each terminus. In each case also one of the sub-stations is located in the power house. In the alternating current proposition the generators are wound for trolley voltage (3,000 volts) and feed directly into the trolley. In each case, also, there are supposed to be four feeding points beside the power house, thus making the sub-stations 12 miles apart in both cases.

Further, in both cases the secondary system is a single network, thus gaining the advantage of two feeding points.

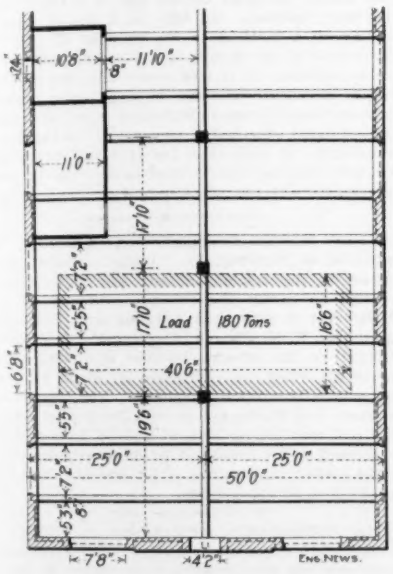
Direct Current Railway System.	Alternating Current Railway System.
POWER REQUIREMENTS.	
Average KW. at car in typical 2-mile run (Fig. 1).—67.2 KW.	Average real KW. at car in typical 2-mile run (Fig. 2).—73.9 KW.
No. cars running at one time.—8.	No. cars running at one time.—8.
No. sub-stations.—5.	No. sub-stations.—5.
Average No. cars per sub-station.—1.6.	Average No. cars per sub-station.—1.6.
$\sqrt{\text{mean}^2}$ amps. per car.—185.3.	$\sqrt{\text{mean}^2}$ apparent KW. per car.—129.0.
	$\sqrt{\text{mean}^2}$ amps. per car (3,000 volts).—43.0.
$\sqrt{\text{mean}^2}$ amps. per sub-station = m. = 279.0	$\sqrt{\text{mean}^2}$ amps. per sub-station = m. = 69.8.
With sub-stations 12 miles apart, 80 lbs. track rail and 60-lb. 3d rail, resistance between adjacent sub-stations is = r.—0.9 ohms.	With sub-stations 12 miles apart, 80 lbs. track rail and No. 0000 trolley wire, resistance between sub-stations allowing for increased rail resistance.—4.2 ohms.
D.-C. line loss per sub-station $\frac{r\,m^2}{6}$ = 161 KW.	Trolley and rail loss per sub-station = $\frac{r\,m^2}{6}$ = 3.32 KW.
Average KW. per sub-station at cars = 67.2 × 1.6 = 107.5.	Average real KW. per sub-station at cars = 73.9 × 1.6 = 118.0.
Average KW. per sub-station at sub-station.—123.6 KW.	Average real KW. per sub-station at sub-station.—121.32 KW.
	Per cent. loss in regulator and car transformer, 5.0%.
Per cent. loss in 3d rail, 15.5%.	Per cent. loss in trolley and rails, 2.8%.
Per cent. loss in step-down transformers, 3.5%.	Per cent. loss in step-down transformers, 3.5%.
Per cent. loss in rotaries, 10%.	
Per cent. loss in high-tension line, 2.5%	Per cent. loss in high-tension line, 2.5%.
Per cent. loss in step-up transformers, 3.5%.	Per cent. loss in step-up transformers, 3.5%.
Total per cent. loss from cars to P. H., 39.5%.	Total per cent. loss, 18.4%.
Average KW. consumed by 8 cars at the cars—537 KW.	Average real KW. consumed by 8 cars at the cars—591 KW.
Average KW. at power house for 8 cars—750 KW.	Average real KW. at power house for 8 cars—700 KW.
	Average apparent KW. at power house, about 825 KW.
Max. load per sub-station—worst condition, 2 cars starting—560 KW.	Max. load per sub-station—worst condition, 2 cars starting (say 275 apparent KW. each)—550 KW.
One 400-KW. rotary will take care of this with 40% overload.	One 350-KW. transformer will take care of this with 50% overload.
Average load on rotary, 30%.	Average load on sub-station, about 40%.
Rotary sub-stations are of sufficient size so that one can be cut out temporarily.	These transformers are sufficiently large to take care of road if one is cut out.
Max. load on power house, say 1,200 KW.	Max. load on power house in apparent KW., say 1,400 KW.
Can be taken care of with three 400-KW. generators—one for spare.	Can be taken care of with three 450-KW. generators—one for spare.
STEP-UP TRANSFORMERS.	
Seven 150-KW. transformers—1 for spare.	Three 400-KW. transformers—load can be carried by 2 in case of emergency.
HIGH-TENSION LINE.	
One No. 6 B. & S. gage line each way from power house, 20,000 volt, 3-phase.	One No. 3 B. & S. gage line each way from power house, 20,000 volt, 1-phase.
Max. loss, about 8.25%.	Max. loss, about 8.2%.
Aver. loss, about 2.50%.	Aver. loss, about 2.7%.
SUB-STATION EQUIPMENT.	
5 sub-stations in all—1 in power house.	4 sub-stations—power house feeds directly into 3,000-volt trolley.
Each of 4 sub-stations to contain:	Each sub-station to contain:
Three 135-KW. step-down transformers.	One 350-KW. transformers.
One 400-KW. rotary converter.	
Switchboard.	Switchboard.
Step-down transformers omitted in power house sub-station.	
LOW-TENSION DISTRIBUTING SYSTEM.	
Entire length of track equipped with 60-lb. conductor rail.	Entire length equipped with No. 0000 B. & S. gage trolley.
CAR EQUIPMENTS.	
Each car equipped with two 150-HP., D.-C. railway motors and multiple control apparatus complete.	Each car equipped with two 165-HP., A.-C. railway motors with multiple control apparatus complete.

Direct Current Railway System.	Alternating Current Railway System.
ESTIMATED FIRST COSTS OF ELECTRICAL EQUIPMENT.	
POWER STATION.	
Three 400-KW. 25-cycle, 360-V., 3-ph. A.-C. generators at $6,500 each $19,500	Three 450-KW., 25-cycle, 3,000-V., 1-phase, 2,000 alternating generators at $7,000 each..... $21,000
Seven 150-KW., 350 to 20,000-V., self-cooling, oil-insulated transformers, 25-cycle, at $1,225. $8,575	Three 400-KW., 17-cycle, 3,000 to 20,000 volts., O. I. S. C. transformers at $2,500 ..... $7,500
Switchboard $4,500	Switchboard $3,500
$32,575	$32,000
HIGH-TENSION LINE.	
48 miles of 20,000-V., 3-phase transmission line, No. 6 B. & S. gage conductors at $900 per mile. $43,200	48 miles of 20,000-V., 1-phase transmission line, No. 3 B. & S. gage conductors at $1,200 per mile $57,600
Lightning protection. $2,500	Lightning protection. $2,000
$45,700	$59,600
SUB-STATIONS.	
12 135-KW., 20,000 & 360-V., 25-cycle, O. I. S. C. transformers at $1,175 each. $14,100	4 350-KW., 2,000 alt., 2,000 to 3,000-V., O. I. S. C. transformers at $2,200 each $8,800
5 400-KW., 600-V., 25-cycle rotary converters at $5,200 each $26,000	5 switchboards at $1,500 each $7,500
5 switchboards at $2,800 each..... $14,000	Auxiliary signaling lines for operating sub-station switches $7,500
$54,100	$23,800
LOW-TENSION DISTRIBUTION SYSTEM.	
63 miles of 60-lb. conducting rail at $2,500 per mile installed $157,500	63 miles of No. 0000 trolley wire in place at $900 per mile..$56,700
Bond main track—63 miles at $400 per mile $25,200	Bonding main track, 63 miles at $400 per mile $25,200
	15 miles of pole construction, not included in high-tension lines, at $630 per mile $9,400
$182,700	$91,300
CAR EQUIPMENT.	
12 D. C. car equipments, complete, consisting of 2 No. 50-C. motors, with multiple control outfit, heaters and contact shoes, at $5,217 each $62,604	12 A. C. car equipments, complete, consisting of 2 165-HP. motors, with multiple control outfit, heaters and trolley, at $8,482 each $101,774
Total first cost of electrical equipment. $377,179	Total first cost of electrical equipment. $308,774
ESTIMATE OF YEARLY OPERATING EXPENSES.	
5 men at power house, two shifts, aver. wage $900 per year each..... $9,000	5 men at power house, two shifts, aver. wage $900 per year each..... $9,000
1 man at each of 4 sub-stations, two shifts, at $900 per year each $7,200	
Fuel, water, oil, etc., at ½ ct. per KW. hour—4,890,000 KW. hours $24,450	Fuel, water, oil, etc., at ½ ct. per KW. hour $23,050
Repairs and maintenance of power house (3% of cost per year) $971	Repairs and maintenance of power house (3% of cost). $963
Repairs and maintenance of H. T. line (5% of cost per year)..... $2,285	Repairs and maintenance of H. T. lines (5% per year) $2,980
Repairs and maintenance of sub-stations (4% of cost per year) $2,064	Repairs and maintenance and inspection of sub-stations (6%).. .... $1,428
Repairs and maintenance of 3d rail (1% of cost per year) $1,822	Repairs and maintenance of trolley (4% per year)..... $3,652
Repairs and maintenance of car equipments (12% of cost per year) $7,512	Repairs and maintenance of car equipments (10%) $10,177
Total yearly operating expenses $55,404	Total yearly operating expenses $51,256

except beyond the end sub-stations. In neither system are secondary feeders figured on, the alternating current being simply a No. 0000 trolley wire throughout, and the direct current a 60-lb. conductor rail. In the direct-current



Cross Section.



Plan.

Fig. 2. Plan and Cross-Section of Brass Shop Showing Arrangement of Beams and Girders and of Test Loads.

system the high-tension line is supposed to be along the right of way of the road and in the alternating current system the high-tension poles are utilized for supporting the trolley wire with a bracket construction.

Recognition of the fact that the alternating-current car is the heavier and requires more energy is made and larger motors than on the direct-current car estimated on.

In the direct-current proposition the generators, transmission line, etc., are supposed to be three-phase, naturally making necessary smaller transformers than in the single-phase system.

The accompanying table gives a complete comparison of the power consumption, the losses in the various transmissions and transformations, the first cost of the apparatus used and an estimate of the operating expenses. The conditions are taken as nearly as possible those in the typical road. Location will of course make differences in many of the items considered, but especial care has been used in estimating those items in which the two systems present a difference.

NOTES ON THE TABULAR COMPARISON.

FIRST COST.—In the first cost of the two systems above compared no allowance is made for the fact that the alternating-current system requires less energy at the power house and therefore will economize to a considerable extent in both engines and boilers. On account of the greater apparent KW. for the alternating-current system, generators and transformers will be larger in capacity, but the engines and boilers need not be so great in capacity. So far as transformers are concerned, the alterating-current system has the advantage because it allows the use of considerably larger units than the direct-current where three-phase transmission is necessary instead of single phase, as is the case in alternating-current system. The alternating-current switchboards also have the advantage in that two switches per panel are required instead of three.

To render a given service over high-tension line, more copper is required for a single-phase line than for a three-phase line; and this makes the copper for the alternating-current system somewhat more expensive than for the direct-current system. The largest difference, however, in the high-tension line items comes from the fact that the poles for the high-tension line are spaced sufficiently close to allow the trolley brackets to be supported from the same poles. In the direct-current system, the spacing need be only sufficient for the requirements of the high-tension line alone.

So far as sub-station transformers are concerned, the alternating-current system has the advantage of single-phase over three-phase in that larger units are used. By far the largest item of saving in sub-station equipment between the two systems is of course in the omission of rotary converters in the alternating-current system.

The greatest difference in first cost of the two systems is, of course, the great difference in the cost of the secondary net work. A glance at the comparative values will show that this difference in the case we have considered amounts to nearly $100,000, and is therefore nearly 30% of the total cost of the electrical equipment.

In first cost the alternating-current car equipments are, of course, considerably higher than the direct current. I would call attention to the fact, however, that the costs of the alternating-current car equipment include an induction regulator. If some other style of regulator, such as, for instance, loops on the car transformers, has been figured upon, the cost of the alternating-current car equipments might be diminished by something like 6%; that is, something over $6,000. The saving in weight by the same change and the consequent saving of power in the alternating-current system would amount to nearly 4% of that which have been figured upon. In the item of maintenance of the control apparatus, however, it is believed that the induction regulator has the advantage in that it is not necessary to break the current in going from step to step.

The alternating-current system throughout is figured on the basis of using a frequency of 2,000 alts. per minute. This frequency could be increased to, say, 3,000 alts. per minute at the expense of, first, a considerably decreased power factor and consequently increased apparent KW.; second, increased generator and transformer capacity; third, increased line and rail loss; and, fourth, increased cost of motors. This difference might run the cost of the alternating-current car equipment some 5% higher than figured on. It will be noted that the great saving comes in changing from direct current to alternating current, and that a change in frequency within moderate limits effects a change by no means comparable with that which is affected by going to alternating current.

OPERATING EXPENSES.—In the labor item it will be noted that the main saving comes in that sub-station attendance is avoided by the use of the alternating-current system. In other respects the labor items will be the same.

The fuel item for the alternating-current system is somewhat smaller than for the direct-current system, as the actual energy at the power house is less in the former case than in the latter.

Besides labor and power, the main operating expense for any interurban railway system comes in the items of repairs and maintenance. It will be noted that this item of repairs and maintenance has been included in the above comparison by assuming that it is a certain percentage of the first cost in each case. There may be some difference of opinion as to the percentage that should be assumed in the various cases of this item of repairs and maintenance, but I have endeavored to make the comparisons between the two systems as fair as possible. It is not intended to include any item of depreciation in these repairs and maintenance figures. It will be noted that a marked difference is made between the maintenance of a third rail and trolley by allowing 1% in the one case and 4% in the other. The apparent discrepancy in allowing 5% for the maintenance and repairs on the high-tension line and only 4% for that of the trolley is explained by the fact that the 5% on the high-tension line includes the repairs and maintenance and the supporting structure for the trolleys.

The matter of inspection of the alternating-current sub-stations is taken care of by allowing 6% in the case of the alternating-current sub-stations instead of 4% as in the direct-current sub-stations.

In the matter of repairs and maintenance of the car equipments, it will be noted that 12% is allowed in the direct-current system and only 10% in the alternating-current system. Even this difference in percentage allows $10,000 per year for the maintenance of the alternating-current equipments in the place of $7,500 for the direct current, or 25% more for the alternating current than for the direct current. The alternating-current motors being lower in voltage and being protected from direct lightning discharges by the intervention of a transformer ought to have at least a no higher maintenance bill than the direct-current motors. The number of motors in each case is the same. The alternating-current system, however, will require a certain amount of attention for the transformers and regulators. This item, though necessarily not based on experience, is estimated to represent the comparative conditions as closely as is possible at this time.

FAILURE OF A REINFORCED CONCRETE FLOOR UNDER TEST AT TRENTON, N. J.

A disastrous failure of a reinforced concrete mill floor under test occurred at Trenton, N. J., on Dec. 8. The floor being tested was one of the floors of the brass shop of the new J. L. Mott iron works, now in course of construction. Full details of the floor construction are not yet available, and it is impossible, therefore, to discuss the real cause of the accident. These details we hope to be able to give in our next issue. Meanwhile we present as a matter of news the following account of the accident sent to us in response to our request by the Baltimore Ferro-Concrete Co., Baltimore, Md., the designers and contractors for the floors:

The brass shop where the accident occurred is one of the five buildings that the J. L. Mott Iron Works are erecting in Trenton, N. J. It is 300 ft. long × 50 ft. wide and has four reinforced concrete floors and a concrete roof resting upon the brick walls, and one row of concrete pillars. The enclosed plan and section show the dimension of the various parts of the building which is completed and was to be submitted to test loads. The floors were designed for a live load of 250 lbs. per sq. ft. and the specifications called for tests of twice the superimposed load.

FIG. 1. VIEW SHOWING TEST LOAD SAFELY CARRIED BY SECOND FLOOR OF BRASS SHOP OF J. L. MOTT IRON WORKS.

The reinforced concrete used in this building consists of plain round steel bars, part of which are straight and part bent; they are bound to the slab forming the floor by means of ties or binders made of ¼-in. steel bars.

The photograph, Fig. 1, shows the successful test made on the second floor. A surface of 30 × 30 ft. was loaded with 4,500 bags of sand weighing 225 tons; the main girder showed a deflection of 3-16-in. and the secondary beams 7-16-in. On the third floor a surface of 40 ft. 6 ins. × 16 ft. 6 ins. was tested, as shown on the diagram, and had to carry a load of 180 tons. About 150 tons were piled up on Dec. 7 and were allowed to remain the whole night. On Dec. 8 the balance of the test load had been put on the floor, all but ten bags, when suddenly the concrete began to crack and the part of the floor submitted to the test broke in, fell on the second floor, which was crushed, and then on the first, where, unfortunately, two men were passing. They were killed instantly.

An examination of the wreck shows that the concrete was sound and without any holes, the stones being broken, as well as the mortar. A great part of the concrete floor remained suspended in the air with the steel rods. None of these rods appeared to be broken, but the rods of the secondary beams, 23 ft. in span, were pulled out of the walls on which they had a bearing surface of only 12 ins. Some of these beams are not broken.

We are of the opinion that these secondary beams gave way first and parted from the walls, as we found that most of the bags of sand used in the test were piled in the cellar along these walls.

The main girders between columns were broken, but remained in place. The columns were not injured at all and their footings showed no settlement. The walls are slightly buckling inside. Very few cracks are oblique.

The accident proves that when a concrete beam 23 ft. in span is to be submitted to a test equivalent to the weight of two locomotives on the third floor of a building, it must have upon the brick wall a bearing surface of more than 12 ins. in order to obtain a sufficient anchorage of the steel rods into the walls.

We have just received the report that a new test was made on Dec. 12 on the third floor, part of which failed on Dec. 8. The load applied was 151 tons and was concentrated in the middle of the building and far from the walls. The test was successful, giving a deflection of 2-16-in. on main girder and 3-16-in. on secondary beams.

THE CANVASS OF THE N. Y. BARGE CANAL VOTE shows that at the recent election, there were 673,910 votes cast in favor of the Barge Canal, 427,698 votes against, and 158,069 void or blank. It is interesting to note that in Greater New York city alone there were 444,800 votes for and 55,729 votes against the $101,000,000 canal. Of the votes cast against the measure it will be seen that 372,969 or nearly 90% of the total "No" votes came from the cities and counties outside of Greater New York; whereas Greater New York alone furnished nearly 70% of the total "Yes" votes. In Greater New York there were 8 votes in favor of the Barge Canal to every 1 against; while in Buffalo, the western terminus, the ratio was less than 5 to 1. But the most striking feature of the Buffalo vote was that more than 40% of the voters refused to vote at all upon the measure. The vote in Erie county (Buffalo) was 39,451 for, 8,355 against, and 33,852 blank or void votes. With one notable exception all the daily papers in New York favored the Barge Canal, and the Buffalo papers were equally unanimous. Rochester, the third largest city in the state, cast 5,247 votes for, 21,443 against, and 750 blank. While Rochester is now on the Erie Canal, it will cease to be if the proposed location is adhered to.

THE CHICAGO SANITARY DISTRICT at its annual meeting on Dec. 8 reported that at the beginning of the year four of its Chicago River bridges were in operation, while three more have been completed, two are under contract, and plans are being prepared for four more. The principal part of the construction work done during the year has been in widening and deepening the south branch of the Chicago River. This included 277,426 cu. yds. of dredging and 4,148 ft. of river wall; making a total of 2,941,100 cu. yds. of dredging and 11,761 ft. of wall built since the beginning of this river improvement work in 1897. The District has also adopted plans for the improvement of the north branch of the Chicago River, and the contracts for this work will be let early in January.

WATER POWERS ON THE KENNEBEC FIVER, Maine, have recently been examined by the United States Gological Survey, and show a number of excellent undeveloped water powers. In almost every place where there are plants in operation from one-half to two-thirds of the power still goes to waste.

At Augusta a 17-ft. dam furnishes about 20,000 HP., of which only 4,000 HP. are used. Eighteen miles up the river, at Waterville, two dams use only a trifling part of an available head of 42 ft., and at Fairfield not more than one-tenth of the power of a 16-ft. dam is employed. The same is true of the 12-ft. dam at Shawmut. At Skowhegan, where there is a fall in the river of 20 ft., only 7,000 HP. are used.

Between Norridgewock and Madison there are sites that present good opportunities for power development. For 24 miles above Solon there are a great many rapids and shoals, which have a total fall of 100 ft. Three miles above the Forks, the last settlement up the river, is the first power, on Moxie Stream, with a vertical drop of 85 ft. For four miles below Indian Pond the river gorge is very narrow, with walls about 200 ft. high. In this distance there is a fall of 190 ft., with several excellent sites for power development. The outlets of both Indian Pond and Moosehead Lake are controlled by crib dams that regulate the water for lumbering purposes.

The elevation of Indian Pond was found to be 933 ft. and of Moosehead Lake 1,029 ft.

DOUBLING THE WATER SUPPLY OF THE CITY OF Mexico and extensive improvements in the present waterworks system are proposed by the Mexican Government. Soundings are to be made with this end in view, in the hope of obtaining an underground supply. About 30 holes, each varying from 300 to 400 ft. in depth, will be sunk. The diamond drills and necessary machinery with which to make these soundings have recently been purchased from an American machinery company, which company will superintend this work. The Government's engineer, Mr. Manuel Marroquin, will supervise the operations.

THE SLOW SAND FILTERS connected with the waterworks of Albany, N. Y., removed 99.27% of the bacteria in the applied water during the four years ending Sept. 30, 1903. This figure is on the average of daily counts, holidays and Sundays excepted. For the last year of the four the removal was 99.64%. The maximum and minimum average number of bacteria, by months, in 1902-03 was as follows: January, 56,000 and 299; July, 3,800 and 25; year, 25,600 and 92. The average yearly yield of filtered water per acre in 1902-03 was 2,260,000 gallons. For the foregoing figures we are indebted to Mr. Allen Hazen, M. Am. Soc. C. E., 220 Broadway, New York City, under whose direction the filters were designed and built.

BIDS FOR MUNICIPAL WATER-WORKS were received at Helena, Mont., on Nov. 25, a large number of contractors located all the way from New York to the Pacific Coast entering the competition. The water and light committee recommended that the contract be awarded to the Congress Construction Co., of Chicago, at $579,000. The new supply will be drawn by gravity through a pipe line some 24 miles long, composed of wood stave and vitrified pipe, and 6,800 ft. of 24-in. steel pipe. There will be some 40 miles of pipe within the city. Mr. Charles W. Helmick is city engineer of Helena and Mr. Jas. D. Schuyler, of Los Angeles, has been consulting engineer. A water supply was introduced in Helena by private companies about sixteen years ago. In 1889 the companies consolidated. For some years past the city and the company have been in litigation.

THE MOST SERIOUS RAILWAY ACCIDENT of the week was a passenger wreck on the Chicago, Burlington & Quincy Ry. near Albia, Ia., on Dec. 13, in which five persons were killed. A west-bound passenger train was derailed while crossing a bridge. The wreck and the subsequent fire in the debris resulted in the death of five passengers. On the same day occurred a wreck on the Baltimore & Ohio Ry., near Piedmont, W. Va., which counts an equal number of victims, but which we place second because it involved freight trains in place of passenger trains. A double-headed freight train was derailed while going down a long grade, and most of the train went down a high embankment. Five of the trainmen were killed, and one or two others perhaps fatally injured. It is to be noted that both of these wrecks involved only one train each, and the wreck was caused by a derailment in both cases.

A LONG-SPAN CONCRETE FLOOR fell during construction in a building being erected in Pittsburg, Pa. The floors were of expanded metal and cinder concrete; the building is eight stories in height. We are informed that while a section of the roof concrete was being placed the supports of the forms failed and the uncompleted section fell. The corresponding sections in the two tiers immediately below had not yet been put in, so that the mass of concrete fell three stories before striking a floor. The falling mass went through all the floors to the basement, killing one man.

THE DEBRIS BARRIERS IN YUBA RIVER, Cal., have been destroyed by a recent freshet. These barriers, or brush dams, were described in our issue of Jan. 15 last. It appears from reports that the upper barrier had been completed, but the lower dam east of Marysville was still under construction. The direct cause of destruction of the upper barrier appears to have been the battering of the crest by snags and logs. The members of the California Debris Commission are making an investigation of the cause of the destruction of the barriers.

THE LANGLEY AIRSHIP appears to be a thorough disappointment. The first attempt to induce the machine to fly was made some months ago at Widewater, Va., on the Potomac River, but the airship went into the water only a short distance from the ways whence it was launched. A projection on the launching track was charged with this failure. On Dec. 8 a second attempt was made on the Potomac, near Washington; the conditions of wind and weather were in every way satisfactory. F. M. Manley, assistant to Prof. S. P. Langley, manned the machine and started the motors. According to the news reports, the vessel tilted when it reached the end of the launching ways, and fell into the water. Manley narrowly escaped drowning. This airship has been in process of construction for a year or more. The cost of its construction and of preliminary experiments on air-resistance and mechanical flight was partly met by the Smithsonian Institution, of Washington, D. C., of which Professor Langley is secretary, and by a subsidy from the Board of Ordnance and Fortification of the War Department.

BUILDING OPERATIONS HAMPERED BY DYNAMITE is the most recent phase of the building contract situation in New York City. During the entire past summer labor troubles practically paralyzed building construction in that city, but two or three months ago the intolerant attitude of one faction of building trades workers caused a split among the labor unions, and as a result work was gradually resumed. On Dec. 12 a derrick used in the erection of a building in the Borough of Brooklyn fell on account of the failure of a guy-rope, and did considerable damage. It is now stated that the accident was due to malicious loosening of a guy-rope clamp. The following night dynamite explosions occurred in two buildings, situated over half a mile apart, in the Borough of Manhattan. In both cases the explosive was placed near the main hoisting engine used in erecting the steelwork, presumably with the intention of disabling the engine.

A NEW WATER FILTRATION COMMISSION has been appointed at Pittsburg, Pa. Under a resolution recently passed by the common council the commission is instructed to verify the revised estimates of the cost ($7,500,000) of slow sand filtration submitted some time ago by Mr. E. M. Bigelow, Director of Public Works, and to report on the size and character of a plant sufficient to supply the whole city, including the South Side, which is now served by a private company. The inquiry is to cost not more than $5,000, and is to be finished by Feb. 1, 1904. It is said that the epidemic of typhoid fever at Butler has so aroused public sentiment as to cause some real action in the matter of filtration, which has now been projected and delayed for many years.

THE OUTBREAK of typhoid fever at Williams College in Williamstown, Mass., noted in these columns a few weeks ago, has been reported on as follows by Mr. Geo. A. Soper, Ph.D., Assoc. M. Am. Soc. C. E., of 29 Broadway, New York City:

> The recent outbreak of typhoid at Williams College was caused, in my opinion, by infected cream eaten with breakfast food. Investigation shows that the cases may all be attributed to cream obtained from one can, and this can probably became contaminated by impure water which accidentally entered it from a vat in which the can was placed to cool.
>
> The cream in question came from out of town. The total number of cases was not high, which was presumably largely due to the prompt steps taken to prevent the spread of the outbreak by secondary infection.

ONE OF THE ST. LOUIS BRIBERY CONVICTIONS has been reversed by the Supreme Court of Missouri, on the ground that the persons whom the bribe was intended to influence had no authority to award the desired contract. The conviction was against Col. Edward Butler, who was accused of offering $2,500 to Dr. Henry M. Chapman, a member of the St. Louis Board of Health, for the influence of the latter in the award of a contract for garbage reduction to the St. Louis Sanitary Co. The penalty fixed as a result of a jury trial was three years in the penitentiary. The unanimous opinion of the court was that authority to award the contract was vested in the Board of Public Improvements, and that members of the Board of Health could not be bribed to do what they had no legal authority for doing. It appears, however, that the Board of Health did award the contract in question; and that it awarded a contract for garbage collection to the Excelsior Hauling Co., said to be another Butler concern. It is stated that under the contracts so awarded, the garbage of St. Louis has been collected and treated for several years, and that the contracts still have some eight months to run. The interesting question has been raised whether the decision that freed Butler also releases the city from the contracts named. Other indictments for bribery are still pending against Butler.

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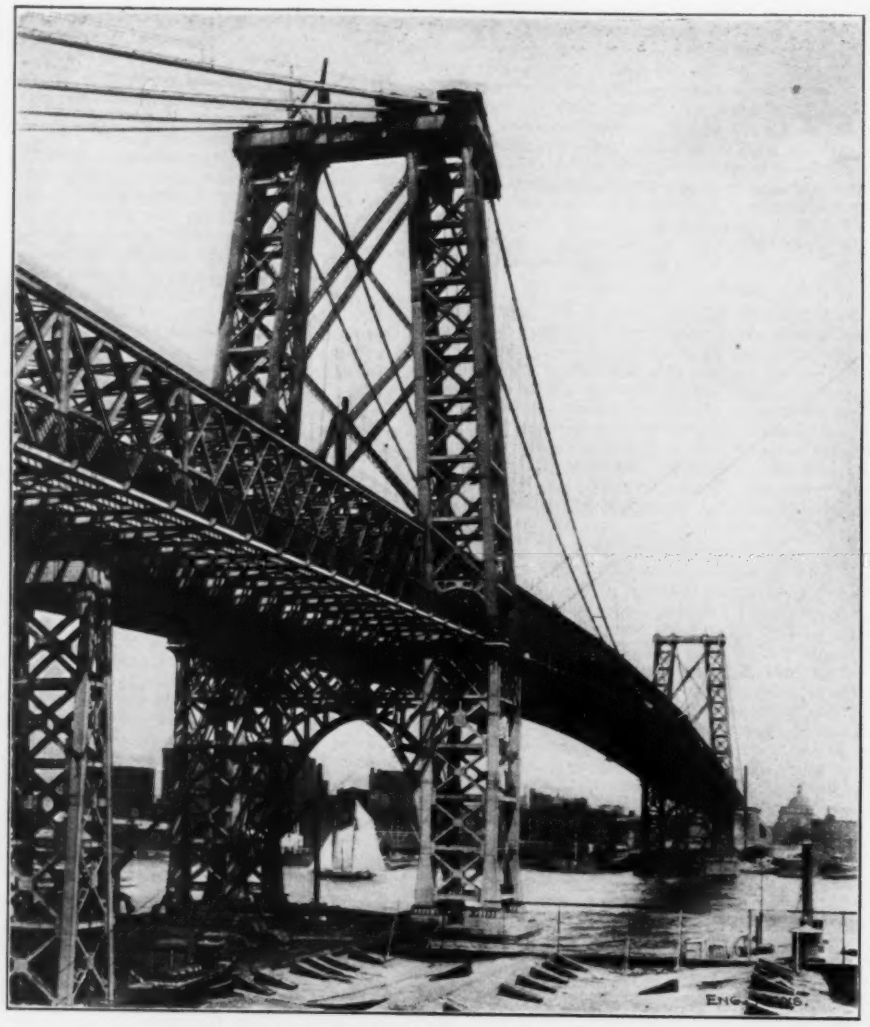

GENERAL VIEW OF BRIDGE FROM MANHATTAN SIDE

GENERAL VIEW OF BRIDGE FROM DOWNST

VIEW SHOWING FOOT-BRIDGES FOR CONSTRUCTING

VIEW ALONG PASSAGE FOR TROLLEY CAR TRACKS

THE WILLIAMSBURG BRIDGE
ACROSS THE EAST RIVER AT NEW Y

L. L. Buck, M. Am. Soc. C. E., Chief Enginee
Gustav Lindenthal, M. Am. Soc. C. E., Commissioner o

Contractors

New Jersey Steel & Iron Co., Trenton, N. J., Towers
Pennsylvania Steel Co., Steelton, Pa., Approaches an
John A. Roebling's Sons Co., Trenton, N. J., Cables

BRIDGE FROM DOWNSTREAM

FOR CONSTRUCTING MAIN CABLES

MSBURG BRIDGE

VER AT NEW YORK CITY

E., Chief Engineer, 1895-1902
E., Commissioner of Bridges, 1902-1904

tractors:

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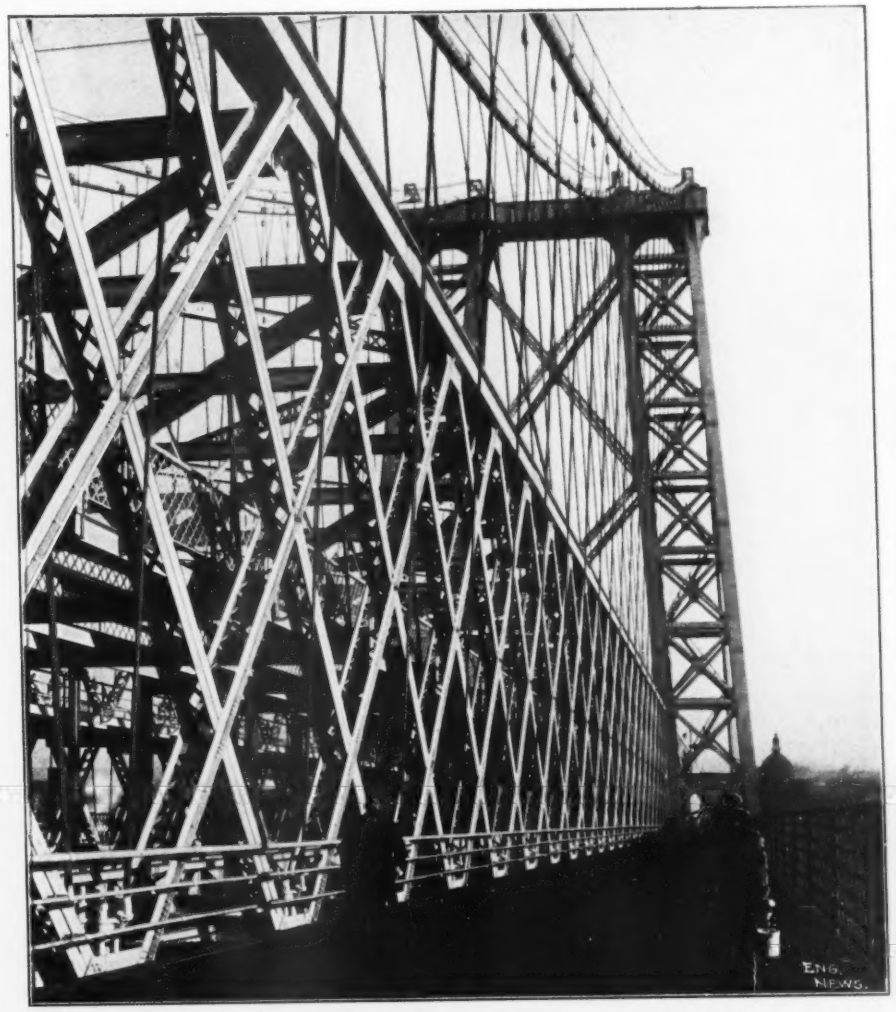
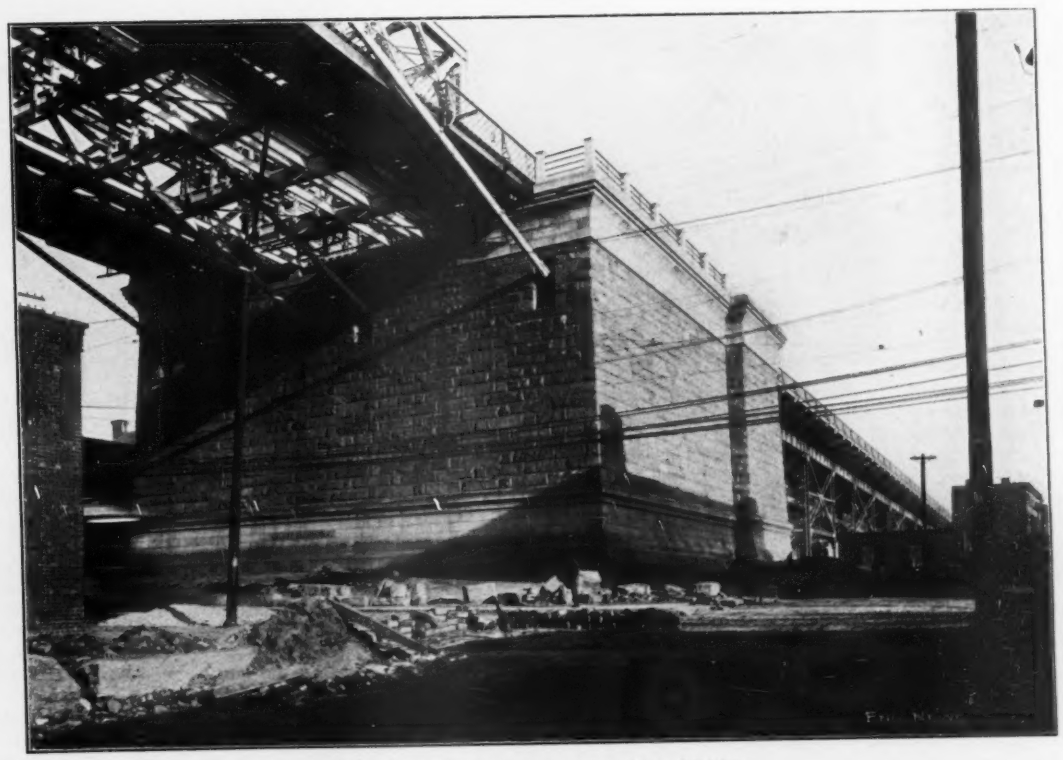


VIEW SHOWING PORTION OF SUSPENDED SPAN TRUSS AND BROOKLYN TOWER FROM ROADWAY



VIEW SHOWING BROOKLYN ANCHORAGE